EVALUATION OF THE POTENTIAL FOR THE APPLICATION OF FLUE GAS CONDENSING SYSTEMS TO GAS-FIRED INDUSTRIAL BOILERS

FINAL REPORT

114 pp

CANMET PROJECT NUMBER: 507802

DSS FILE NUMBER: 07SQ.23440-4-9305

DSS CONTRACT SERIAL NUMBER: 0SQ84-00418

CANMET SCIENTIFIC AUTHORITY: A.C.S. Hayden

MICROMEDIA

KENT ENGINEERING LTD., Vancouver, B.C.

November 1985

FOREWORD

Boiler flue gases contain varying amounts of water vapour depending on the fuel used. The latent heat of this uncondensed moisture contributes substantially to stack heat losses with fuels of high hydrogen content such as natural gas. A significant amount of the flue gas sensible and latent heat losses may be recovered by use of specially designed condensing heat exchangers.

Energy Mines and Resources Canada carried out a number of studies in 1985 to evaluate the potential for the application of flue gas condensation systems to gas-fired industrial boilers.

This study at the J & L Meats Company Ltd. plant at Surrey, B.C., supplemented by studies at two greenhouse operations in the B.C. Lower Mainland, was conducted under the auspices of the Canada Centre for Mineral and Energy Technology (CANMET), Energy Mines and Resources Canada by Kent Engineering Ltd.

TABLE OF CONTENTS

	Page
FOREWORD	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	v
LIST OF FIGURES	vi
SYMBOLS, ABBREVIATIONS AND CONVERSION FACTORS	vii
1.0 SUMMARY CONCLUSIONS AND RECOMMENDATIONS	1
1.0 SOMMAIRE, CONCLUSIONS ET RECOMMANDATIONS	3
2.0 INTRODUCTION	
2.1 BACKGROUND	5
2.2 PURPOSE OF STUDY	6
2.3 MAJOR OBJECTIVES AND SCOPE OF WORK	6
2.4 NATURAL GAS CHARACTERISTICS AND COMBUSTION FUNDAMENTALS	7
2.5 FLUE GAS CONDENSATION FUNDAMENTALS	14
2.6 FLUE GAS CONDENSATION HEAT RECOVERY	17
2.6.1 Condenser Heat Transfer Performance	17
2.6.2 Condenser Types	22
2.6.3 Condenser Efficiency	27
3.0 EVALUATION OF EXISTING FLUE GAS CONDENSATION INSTALLATIONS	
3.1 INTRODUCTION	29
3.2 SITE NO. 1	30
3.2.1 Description of Boiler and Condenser	30
3.2.2 Evaluation of System Performance	31
3.3 SITE NO. 2	32
3.3.1 Description of Boiler and Condenser	32
3.3.2 Evaluation of System Performance	32
3.4 SITE NO. 3	33
3.4.1 Description of Direct-Contact Flue Gas Condensation System	33
3.4.2 Process Conditions	33

TABLE OF CONTENTS - cont'd.

		Page
4.0	POTENTIAL FOR FLUE GAS CONDENSATION HEAT RECOVERY AT STUDY PLANT	
	4.1 DESCRIPTION OF PLANT	34
	4.2 WATER AND NATURAL GAS CONSUMPTION	36
	4.3 BOILER EFFICIENCY TESTS	39
5.0	EVALUATION OF FLUE GAS CONDENSATION HEAT RECOVERY SYSTEMS FOR STUDY PLANT	
	5.1 INTRODUCTION	42
	5.2 DESCRIPTION OF SYSTEMS	44
	5.2.1 Steam Boilers System	47
	5.2.2 Hot Water Boiler System	50
	5.3 SYSTEMS DESIGN	51
	5.4 ECONOMIC ASSESSMENT	57
	5.5 FURTHER DISCUSSION AND CONCLUDING COMMENTS	58

APPENDICES

APPENDIX A - Performance Test Report of Flue Gas Condenser at Site No. 1 by B.C. Hydro

APPENDIX B - Performance Test Report of Flue Gas Condenser at Site No. 2 by B.C. Hydro

APPENDIX C - Flow Diagram and Equipment Photographs for direct Contact, Flue Gas Condensation Heat Recovery System at Site No. 3.

APPENDIX D - Typical Water Heating Circuits for Surface Flue Gas Condensers

APPENDIX E - Direct Contact Flue Gas Condenser as Marketed by Rocket Research Company

APPENDIX F - Illustrations of Surface Flue Gas Condensers Available from Holland

LIST OF TABLES

		Page
TABLE 1	- Summary of Calculations of Combustion Air Requirement and Products of Combustion for Stoichiometric Combustion (for B.C. Hydro Natural Gas)	1
TABLE II	- Summary of Calculations of Flue Gas Dew-Point Temperatures for Different Levels of Excess Air (for B.C. Hydro Natural Gas)	18
TABLE III	- Stack Losses Without Flue Gas Condensation (for Groningen Natural Gas, Holland)	23
TABLE IV	- Summary of Performance and Economic Data for Two Existing Flue Gas Condensation Systems - Site No. 1 and Site No. 2	30-a
TABLE V	- Water Consumption Record	38
TABLE VI	- Natural Gas Consumption Record	38
TABLE VII	- Consumptive Distribution of Water and Natural Gas	41
TABLE VIII	- Design and Economic Evaluation Summary for Condensation Heat Recovery Systems	54

LIST OF FIGURES

		Page
FIGURE 1	- Dew Point Temperature of Flue Gas from Natural Gas (B.C. Hydro Natural Gas)	19
FIGURE 2	- Characteristics of Natural Gas Combustion (For B.C. Hydro Natural Gas)	20
FIGURE 3	- Typical Relationship Between Boiler Combustion Efficiency and Return Water Temperature for Condensing Boilers	21
FIGURE 4	- Typical Relationship Between Flue Gas Temperature Leaving Condenser, Excess Air and Heat Recovered by Flue Gas Condenser.	24
FIGURE 5	- Relationship Between Flue Gas Heat Recovered by Flue Gas Temperature Excess Air and Heat Recovered by Flue Gas Condenser (For B.C. Hydro Natural Gas)	25
FIGURE 6	- Typical Direct Condensation Heat Recovery System Flow Diagram	28
FIGURE 7	- Plant Photographs - J & L Meats Co. Ltd.	35
FIGURE 8	- Flow Diagram of Steam and Hot Water Service	37
FIGURE 9	- Physical Configuration of Flue Gas Condensers	46
FIGURE 10	- Flow Diagram of Condensation Heat Recovery System for Steam Boilers	48
FIGURE 11	- Flow Diagram of Condensation Heat Recovery System for Hot Water Heating Boiler	52

SYMBOLS, ABBREVIATIONS AND CONVERSION FACTORS

SYMBOLS - SI UNITS

N	- Newton (force)
Pa	- Pascal (pressure, stress)
kPa	- Kilopascal (10^3 pascals)
J	- Joule (work, energy, quantity of heat)
kJ	- Kilojoule (10^3 joules)
MJ	- Megajoule (10^6 joules)
kg	- Kilogram (10^3 grams)
g	- Gram
m	- Meter
mm	- Millimeter
mg	- Milligram
kc	- Kilogram calory (10^3 calories)
Nm^3	- Normal meter cubed - i.e. cubic meter(s) at a temperature of 0°C and 101.325 kPa
W	- Watt (power)
kWh	- Kilowatt hour (work)

SYMBOLS - CONVENTIONAL UNITS

Btu	- British thermal unit
ft^3	- Cubic feet
cfm	- Cubic feet per minute
cfh	- Cubic feet per hour
gal	- Gallon (U.S.)
gpm	- Gallons per minute (U.S.)
gph	- Gallons per hour (U.S.)
gpd	- Gallons per day (U.S.)
gr	- Grains
hp	- Horsepower
psig	- Pounds per square inch gauge
psia	- Pounds per square inch absolute

lb. - Pound
in. - Inch
Q - Heat content
cfd - Cubic feet per day

ABBREVIATIONS

OD - Outside diameter
ID - Inside diameter
hr. - Hour
h - Enthalpy
s - Second
ppm - Parts per million
Q - Heat content
yr. - Year
RH - Relative humidity
Hg - Mercury
HHV - Higher heating value
LHV - Lower heating value

CONVERSION FACTORS

SI Units to SI Units

kPa	x 7.500 = mm Hg
kJ	x 0.2390 = kc
kJ	x 2.778 x 10^{-4} = kWh

SI Units to Conventional Units

kg	x 2.205 = lb.
MJ/m^3 (dry) (at 101.325 kPa 15°C)	x 26.86 = Btu/ft^3 (dry) (at 14.73 psia and 60°F)
N	x 0.2248 = lb. force
MJ	x 948.4 = Btu
kPa	x 0.1450 = $lb./in.^2$ (or psi)
kJ/kg	x 0.4299 = Btu/lb.

1.0 SUMMARY CONCLUSIONS AND RECOMMENDATIONS

Potential for application of flue gas condensation to industrial boilers usually exists where there is available a usable low temperature heat sink, such as water in a closed heating circuit with low return temperature, or low-temperature water that needs to be preheated prior to consumptive use. Typical industries with such potential are slaughter-houses, dairies, laundries and greenhouses.

The heat recoverable by a flue gas condenser is a direct function of flue gas entering temperature, moisture content of flue gas, flue gas dew point temperature and condenser heat exchange surface area, and an inverse function of cooling water entering temperature. High excess air levels in the flue gas depress dew point temperatures and have an adverse effect on condensation of flue gas moisture and hence on heat recovery in the condenser.

The development of flue gas condensation technology and equipment has progressed much further in Europe than in North America. Condensing boilers and flue gas condensers for retrofit to boilers are readily available in Europe - whereas in North America there are few sources of supply, especially for boilers in the small to average size range.

The study plant for purposes of this work is the J & L Meats Company Ltd. meat packing plant in Surrey, B.C. Existing flue gas condensation systems at two greenhouses in the B.C. Lower Mainland - designated as Site No. 1 and Site No. 2 - were also studied to provide a data base for performance estimation and comparison for the study plant.

A summary of performance and economic data for the existing flue gas condensation systems at Site No. 1 and Site No. 2 are found in Table IV. Corresponding calculated data for the study plant appear in Table

VIII; system flow diagrams appear in Figure 10 and Figure 11. Data for the existing systems are comparable to data calculated for the study plant systems, once differences in operating conditions are taken into account. Critical performance and economic data for two proposed condensation heat recovery systems are listed below.

Item	Steam Boilers System	Hot Water Heating Boiler System
Existing combustion system eff. % of HHV	81.4 (Ave.)	78.5
New combustion system eff. % of HHV	95.0 (Ave.)	93.7
Fuel saving, %	14.2 (Ave.)	16.2
Decrease in standby losses, %	0	4.0
Total fuel savings, %	14.2 (Ave.)	20.2
Value of annual fuel savings, $/yr.	4,649	6,958
Capital cost of system	8,198	10,758
Operating cost, $/yr.	140	230
Simple payback period, yr.	1.8	1.6

The above simple payback periods are with the boilers operating roughly 33 percent of total time. If the operating times of boilers were, for example doubled, simple payback periods would be reduced to one half of above values. The payback periods are attractive and hence implementation of the system is recommended.

1.0 SOMMAIRE, CONCLUSIONS ET RECOMMENDATIONS

Le potentiel pour l'utilisation de condensation de fumées dans les chaudières industrielles existe habituellement si un récepteur à basse température est disponible, tel que l'eau d'un circuit fermé où la température de retour est basse, ou de l'eau à basse température qui doit être préchauffée avant utilisation. Des industries typiques qui remplissent ces conditions comprement: abatoirs, laiteries, lessieries et serres.

La quantité de chaleur récupérable par un condensateur de fumée est directement relative à la température d'entrée des fumées, à leur degré d'humidité et point de rosée, à la surface totale de l'échangeur de chaleur du condenseur, et inversement relative à la température d'entrée de l'eau à traiter. Un niveau élevé d'air dans les fumées abaisse la température du point de rosée, a un effet adverse sur la condensation de l'humidité des fumées, et donc sur la récupération de chaleur dans le condenseur.

Le developpement de la technologie et de l'équipement pour la technologie de condensation des fumées a progressé beaucoup plus en Europe qu'en Amérique du Nord. Des chaudière condenseuses et des condenseurs de fumées pouvant être ajontés à des chaudières en existance sont facilement disponible en Europe, alors qu'en Amérique du Nord il n'y a que peu de sources d'équipement, spécialement pour les petites et moyennes chaudières.

L'entreprise utilisée pour cette étude est J. & L. Meats Company, emballage de viandes à Surrey, B.C. Les systèmes de condensation de fumées dans deux serres du Lower Mainland, désignées comme site 1 et 2, ont également été étudiés pour fournir un point de référence pour évaluer l'efficacité du sujet d'étude.

Un sommaire d'efficacité et des données économiques pour les systèmes existants de condensation de fumées aux sites 1 et 2 sont présentés dans la Table IV. Les chiffres calculés correspondants pour l'entreprise étudiée se

trouvent sur la Table VIII. Les schémas des systèmes se trouvent dans les illustrations 10 et 11. Les données des systèmes existants sont comparables aux données calculées pour l'entreprise étudiée, si les différences de conditions d'opération sont prises en compte.

Les données économiques et d'éfficacité pour deux systèmes proposés de récupération de chaleur par condensation sont indiquées ci-dessous.

Item	Système de chaudière à vapeur	Système de chaudière de chauffage à eau chaude
Système efficacité de combustion existante, % de HHV	81.4 (Ave.)	78.5
Système efficacité de combustion nouvelle, % de HHV	95.0 (Ave.)	93.7
Economie de carburant, %	14.2 (Ave.)	16.2
Diminution de pertes auxillaires, %	0	4.0
Economie totale de carburant, %	14.2 (Ave.)	20.2
Valeur de l'économie de carburant, $/an	4,649	6,958
Coût d'installation du système	8,198	10,758
Coût d'opération, $/an	140	230
Période de remboursement simple, années	1.8	1.6

Les périodes de remboursement simple ci-dessus sont calculées avec les chaudières opérant environ 33% du temps. Si les périodes d'opération sont doublées, les périodes de remboursement diminuent de moitié. Les périodes de remboursement sont attirantes, et de ce fait la mise en service de ce système est recommandée.

2.0 INTRODUCTION

2.1 BACKGROUND

Heat recovery from combustion flue gases has traditionally been limited by the water and acid dew point temperature of the flue gases. Conventional economisers recover sensible heat in temperatures well above dew point temperatures to avoid moisture and acid condensation and consequent corrosion of heat exchange surfaces and flue ways. Furthermore, in the case of atmospheric burner equipped boilers, such boilers depend, as usually required by regulations, on high-temperature flue gases for natural draft to vent the gases to atmosphere without condensation forming in the chimney. As a result, a considerable amount of sensible heat of the flue gases and all of the latent heat of the flue gas moisture are lost to the atmosphere. The latent heat loss of moisture in the flue gas is particularly high for natural gas because of the high hydrogen content of this fuel as compared to say fuel oil (typically 12% vs. 6%). Even if the above constraints did not exist, not all boiler applications are able to take advantage of the additional heat recovery by cooling flue gases below moisture dew point temperature because of the lack of a usable low-temperature heat sink - e.g. water at a supply temperature of 40°C for heating with a return temperature of 30°C. There are, however, a number of boiler applications in industry with usable low-temperature heat sinks such as certain water heating circuits (e.g. ground heating in greenhouses) and the preheat of fresh water for high warm and hot water consumers (e.g. slaughter houses and laundries) which can take advantage of flue gas condensation heat recovery through the use of specially designed heat exchangers that cool flue gases below moisture dew point temperatures.

The development and application of flue gas condensing heat exchangers, sometimes referred to as "total economisers", has progressed much further in Europe, particularly in countries such as Holland, than in

North America. The main reason appears to be higher energy costs and more limited energy supplies. Although fuel is in greater supply and available at a lower cost in Canada, price and supply are concerns, as evidenced by the number of energy conservation programs undertaken by governments and industry in recent years. An evaluation of the potential for application of flue gas condensing systems to gas-fired industrial boilers to increase fuel use efficiency would be a significant contribution to the aims of such programs.

2.2 PURPOSE OF STUDY

The purpose of this work is to provide a detailed pre-engineering evaluation of the potential for application of flue gas condensing systems to natural gas fired industrial boilers at the meat packing plant of J & L Meats Company Ltd., Surrey, B.C. This evaluation is supplemented by an evaluation of boilers at two other sites, already making use of flue gas condensation heat recovery, to provide a data base source.

2.3 MAJOR OBJECTIVES AND SCOPE OF WORK

The major objectives and tasks of this work are the following:

1. Determination of the operational characteristics of industrial boiler installations at J & L Meats Co. Ltd. including combustion system efficiencies, flue gas composition and temperature, design of flue gas systems and identification of potential low temperature heat sinks for utilization of waste heat.

2. An analysis of existing performance data or measurement of the performance of existing industrial boiler installations already making use of flue gas condensation heat recovery at two separate sites to provide a data base for performance estimation for the study plant (i.e. J & L Meats Co. Ltd.).

3. Provide a conceptual design of the retrofit flue gas condensation package including equipment layout, modification of flue gas inlets and stacks, system design, and equipment and installation budget cost estimates together with sources of the proposed equipment and identification of any development needs.

4. Estimation of the performance of the modified boiler including combustion system efficiency, percentage of moisture condensed, flue gas temperature after heat recovery, estimation of energy cost savings and simple payback period.

5. Preparation of a report describing the work carried out including:
   - boiler efficiencies before and after retrofit of flue gas condensers;
   - potential for corrosion of heat exchangers, flue gas ducts and stack;
   - any effects of emissions of pollutants on condenser performance;
   - any engineering problems likely to be encountered;
   - instrumentation and control requirements;
   - possible applications in other similar industries in Canada.

2.4 NATURAL GAS CHARACTERISTICS AND COMBUSTION FUNDAMENTALS

1. Gas Analysis

The following is a typical analysis of natural gas delivered in the Lower Mainland of B.C.

	Volume Percent of Constituent					
CH_4	C_2H_6	C_3H_3	C_4H_4	CO_2	N_2	Total
94.8	2.9	0.8	0.2	0.1	1.2	100.0

Specific gravity (rel. to air = 1): 0.586

2. The Combustion Process

The chemical equation for the combustion of methane may be written

$$CH_4 + 2O_2 = CO_2 + 2H_2O + \text{Heat}$$

Similar equations may be written for the other hydrocarbons.

The maximum amount of heat is generated when there is just sufficient air (which consists of about 21% O_2 and 79% N_2) to complete the combustion process. The ratio of fuel and air theoretically required to achieve complete combustion with no extra air or fuel is the stoichiometric ratio. The quantity of air above that required for perfect combustion is known as excess air. Complete combustion is the burning of fuel constituents to carbon dioxide and water vapour, whether or not excess air is present. Incomplete combustion results in intermediate products such as carbon monoxide (CO), hydrogen (H_2), and aldehydes, in addition to carbon dioxide (CO_2) and water vapour.

3. Heating Values of Natural Gas

The amount of heat released on combustion of a fuel is known as the heating (or calorific) value and is determined experimentally. The heating value of natural gas may be expressed on either a higher or a lower basis.

The higher heating value (HHV) of natural gas is the quantity of heat liberated by the complete combustion of one cubic metre of dry gas at a constant pressure of 101.325 kPa and 15°C with air at the same temperature and pressure in which the products of combustion are cooled to the initial temperature and all of the water formed by combustion is condensed to a liquid state.

The range of higher heating values for B.C. Hydro natural gas is usually between 37 and 39 MJ/m^3 - typically 38.64 MJ/m^3 (1038 Btu/ft^3). Since the products of combustion are not cooled to 15°C in practical combustion applications, the higher heating value is not attained.

Appliance efficiency is usually based on the gross heating value.

The lower heating value (LHV) of a gas has the same definition as the higher heating value, except that the water vapour formed remains in the vapour state and the latent heat of condensation, 2,465 kJ/kg of water vapour, is not recovered.

It is evident that the greater the amount of hydrogen in the fuel the lower the lower heating value. For natural gas, the lower heating value is typically 90% of the higher heating value.

The heating value determined at constant pressure (as above) is numerically equal to the change in enthalpy. The heating value determined at constant volume is numerically equal to the change in internal energy. When there is no change in volume the two values are the same; for most fuels the difference is small and is usually neglected.

Heating values vary with the initial temperature (which is also the final temperature) but the variation is usually negligible. In North America heating values are determined at 15°C (60°F) whereas in Europe the temperature adopted is 20°C (68°F).

The heating value of a fuel gas may be calculated by a simple additive method from the heating values of its constituents. This calculation assumes ideal-gas behavior and hence is subject to slight inaccuracies.

4. Combustion Air Requirements

The volume of air required for stoichiometric combustion, the theoretical air requirement, may be calculated from a gas analysis, as shown in Table 1 for a typical composition of B.C. Hydro natural gas (given in item 1).

TABLE I - SUMMARY OF CALCULATION OF COMBUSTION AIR REQUIREMENT AND PRODUCTS OF COMBUSTION FOR STOICHIOMETRIC COMBUSTION (FOR B.C. HYDRO NATURAL GAS)

	Mixture Before Combustion - m^3			Products of Combustion - m^3			
Constituent	Vol.Gas	O_2 Required	Air Required	H_2O	CO_2	N_2	Totals
CH_4	0.948	1.896	-	1.896	0.948	-	2.844
C_2H_6	0.029	0.102	-	0.087	0.058	-	0.145
C_3H_8	0.008	0.040	-	0.032	0.024	-	0.056
C_4H_{10}	0.002	0.013	-	0.010	0.008	-	0.018
CO_2	0.001	-	-	-	0.001	-	0.001
N_2	0.012	-	-	-	-	0.012	0.012
Dry Air	-	-	9.767*	-	-	7.716	7.716
H_2O (40% RH)	-	-	0.069	0.069	-	-	0.069
	1.000	2.051	9.836	2.094	1.039	7.728	10.861
				Less H_2O			-2.094
				Volume (dry)			8.767

Notes:
1. All volumes are at 15°C and 101.325 kPa per unit volume of natural gas at the same temperature and pressure.

* Dry air required = $\frac{O_2 \text{ required}}{\% O_2 \text{ in air}} = \frac{2.051 \text{ m}^3}{0.21} = 9.767 \text{ m}^3$

Theoretical combustion air required = 9.836 m^3 air/m^3 gas(i.e. air/fuel ratio = 9.836/1).

In most combustion processes, it is impossible to mix the fuel intimately enough with just the theoretical amount of air required for stoichiometric combustion. Excess air must therefore be added to ensure that the gases are completely burned before passing out of the combustion chamber. For the greatest combustion system efficiency, excess air must be kept to a minimum because a significant heat loss can be incurred by heating excess air to the flue gas temperature.

5. Excess Air Factor and Percent Excess Air

The excess air factor, n, is defined as,

$$\frac{\text{Air actually used}}{\text{Stoichiometric air requirement}} = n$$

Then, percent excess air is,

$$100\ (n-1)$$

and volume of excess air is,

$$\text{Volume of stoichiometric air } (n-1).$$

The actual volume of dry flue gases then would be,

Theoretical volume of dry flue gases + volume of dry excess air

6. Combustion Losses

Combustion system losses consist of dry flue gas loss, hydrogen moisture loss and incomplete combustion loss.

a. The dry flue gas loss, which includes the loss due to excess air, is the amount of heat given up by the dry flue gases in cooling from the furnace exit temperature to the temperature of the combustion air.

b. The hydrogen moisture loss is the amount of heat given up by the water vapour in cooling from the flue gas temperature to the temperature of the atmosphere and consists primarily of the latent heat of vapourization.

c. The incomplete combustion loss consists of unburned combustible gases in the flue gases such as carbon monoxide and hydrogen.

7. Flue Gas Analysis

Flue gas analyses are used to indicate air/fuel ratio, the degree of completeness of combustion and combustion efficiency. The analyses are usually based on dry flue gases.

Under perfect combustion, the percentage of carbon dioxide is at a maximum and is known as the ultimate percent CO_2. The percent CO_2 decreases with increase in the percentage of excess air. The relationship between percent excess air and percent CO_2 is given by the expression,

$$\text{Excess air } \% = (U - CO_2)/CO_2 \times 100 \ (P/A)$$

where,

U = ultimate CO_2 concentration, %
CO_2 = CO_2 content of flue gas, %
P = Volume of dry flue gas per unit volume of gas burned in stoichiometric combustion.
A = Volume of dry air required per unit volume of gas burned in stoichiometric combustion.

8. Flue Gas Dewpoint Temperature

Every flue gas has a dewpoint temperature which is a function of percent excess air (which can be determined from O_2 or CO_2 concentration in the flue gas), moisture content of combustion air and composition of the fuel.

Calculations of dewpoint temperatures for B.C. Hydro natural gas for different percentages of excess air with a relative humidity of 40 percent are summarized in Table II, from which a plot of dewpoint temperature versus excess air appears in Figure 1. Dewpoint temperatures were obtained by calculating humidity ratios for the flue gas and use of psychrometric tables. The humidity ratio is the ratio of the weight of water per unit weight of air. Dewpoint temperatures in Table II range from 59.7°C to 47.1°C for excess air in the range of 0 to 100 percent, indicating the strong influence of excess air.

9. Combustion System Efficiency

Combustion system efficiency is defined as:

$$\frac{\text{gross input by fuel - fuel gas losses}}{\text{gross input by fuel}} \times 100\%$$

or,

$$100\% - \%\ \text{flue gas losses}$$

Combustion system efficiency may be calculated from measurements of percent CO_2 and/or percent O_2 in the flue gas and the difference between the temperatures of the flue gas and ambient air (i.e. net flue gas temperature).

10. Boiler Thermal Efficiency

Boiler thermal efficiency is defined as,

$$\frac{\text{Heat absorbed by steam or hot water}}{\text{Heat input by fuel}} \times 100\%$$

or,

$$100\% - \text{heat losses}$$

where heat losses include heat loss in flue gas, heat loss due to unburned fuel and heat loss due to radiation and other unmeasured losses.

2.5 FLUE GAS CONDENSATION FUNDAMENTALS

Basic Principles

The burning of 1 m^3 of natural gas at a pressure of 101.325 kPa and a temperature of 15°C yields about 38,600 kJ (9225 Kc/m^3) of total heat (i.e., HHV).

Referring to Table I and psychrometric tables, the quantity of water formed is,

$$2.094\ m^3 \times 0.010692/0.0140\ kg/m^3 = 1.60\ kg.$$

which has a latent heat of

$$1.600\ kg \times 2465\ kJ/kg = 3,944\ kJ$$

Total heat - latent heat = sensible heat (i.e. LHV)
Sensible heat (i.e. LHV) = 38,600 kJ - 3,944 kJ = 34,656 kJ

$$\frac{LHV}{HHV} = \frac{34,656}{38,600} = 0.90$$

$$LHV = 0.90\ HHV$$

In a standard boiler:

None of the latent heat is recovered, hence the loss in latent heat (as a percentage of HHV) is,

$$\frac{3,944}{38,600} \times 100 = 10\%$$

For a flue gas temperature of 220°C and a CO_2 content of about 8.5 percent the sensible heat loss with the dry flue gases (nitrogen + oxygen + carbon dioxide) would be about 3,474 kJ. Loss in sensible heat (i.e. difference in enthalpies of flue gases at 220°C and 15°C) is,

$$\frac{3,474}{38,600} \times 100 = 9\%$$

Total losses = latent heat + sensible heat
= 10% + 9% = 19%

Combustion system efficiency is,

100% - 19% = 81%

Flue gas losses for temperatures above dewpoint temperatures and for different carbon dioxide concentrations (i.e. excess air) are given in Figure 2 and Table III. Although the values in Table III are derived for Groningen (Holland) natural gas, with a HHV of 35.17 KJ/m^3 (8400 kg/m^3), when expressed as percentages of HHV, they are practically the same as those for B.C. Hydro natural gas obtained from Figure 2.

In a condensing boiler:

The major portion of latent heat and sensible heat is recovered by passing the flue gases through a condenser in which they are cooled to a temperature below their dewpoint after they leave the boiler furnace. The cooling medium is usually water from the boiler heating circuit, a separate heating circuit, a combination of both or fresh water which is preheated for consumptive use as warm or hot water.

Latent heat is recovered from the condensed water vapour. The following figures per m^3 of natural gas are an illustrative example.

	Flue Gas Temp.	Water Content	Latent Heat
Entering Condenser	200°C	1.60 kg	3,944 kJ
Leaving Condenser	35°C	0.55 kg	1,356 kJ
Condensate recovered		1.05 kg	
Latent heat recovered			2,588 kJ

Loss in latent heat = 1,356/38,600 x 100%
= 3.5%

Sensible heat is also recovered. The following figures per m^3 of natural gas are illustrative.

	Flue Gas Temp.	Sensible Heat
Entering Condenser	200°C	3,474 kJ
Leaving Condenser	35°C	625 kJ
Sensible heat recovered		2,849 kJ

Loss in sensible heat = 625/38,600 x 100
= 1.6%

Total losses = latent heat + sensible heat
= 3.5% + 1.6% = 5.1%

Combustion system efficiency now is,

100% - 5.1% = 94.9%

The combustion system efficiency of a condensing boiler is dependent on the return water temperature, all other conditions being fixed. The relationship between combustion system efficiency and boiler return water temperature passing through the condenser for condensing boilers of one Dutch manufacturer (Remeha Fabrieken B.V.) in sizes of up to 1,380 kW (4,713,000 Btu/hr) input capacity is shown in Figure 3.

Increasing excess air lowers the flue gas dewpoint temperature which is undesirable for condensing flue gases because lower temperature and less readily available (in industry) cooling fluids are needed to recover a given quantity of latent heat. Stated otherwise, with a cooling medium of a given temperature, less moisture will be condensed and less latent heat recovered from a flue gas with a high excess air percentage than from one with a low excess air percentage. From the point of view of flue gas condenser performance, a low percentage of excess air is desirable.

2.6 FLUE GAS CONDENSATION HEAT RECOVERY

2.6.1 Condenser Heat Transfer Performance

The heat recovered by a flue gas condenser can be readily determined from a measurement of the dry CO_2 concentration, the inlet temperature (T in) and outlet temperature (T out) and use of a chart such as shown in Figure 4. Figure 4 is a typical plot of the heat recovered, expressed as a percentage of the HHV of the fuel used, versus outlet temperature for a carbon dioxide concentration in the flue gas of 10.5 percent (dry). For T in = 140°C and T out = 40°C the indicated heat recovery is 10.5 percent of HHV. For temperatures above 60°C, note that for every 24°C decrease in flue gas temperature, the corresponding increase in recovery is 1 percent of HHV. Therefore, for every 24°C increment in entering temperature the recovery is 1 percent more than indicated - e.g. for 200°C entering temperature the heat recovered is 2.5 percent more than indicated on the chart, i.e. 13.0 percent of HHV.

The above latter figure of 13.0 percent may be arrived at in an alternate way. Table III gives stack losses for different flue gas temperatures and dry CO_2 concentrations based on a combustion air temperature of 20°C. Referring to Table III the stack losses for a CO_2 concentration of 10.5 percent are 18.5% of HHV at 200°C and 16.0% of UCV at 140°C. As previously, the flue gas in cooling from 140°C to 40°C gives up 10.5% of HHV. The total heat recovered then is,

$$(18.5\% - 16.0\%) + 10.5\% = 13.0\% \text{ of HHV.}$$

Figure 4 shows a curve for only one CO_2 concentration (10.5%) applicable to natural gas from the Groningen field in Holland. Obviously, a family of curves can be plotted for other CO_2 concentrations or excess air percentages for other natural gases. Figure 5 is a plot of calculated values of heat recovered by flue gas condensation of flue gases at different temperatures and excess air percentages applicable to B.C. Hydro natural gas.

TABLE II - SUMMARY OF CALCULATIONS OF FLUE GAS DEW-POINT TEMPERATURE FOR DIFFERENT LEVELS OF EXCESS AIR (FOR B.C. HYDRO NATURAL GAS)

COMBUSTION AIR		FLUE GAS			
Ex. Air %	R.H. %	CO_2 % (Dry)	Total Vol. m^3/m^3 of fuel	Vol. of Water Vap. m^3/m^3 of fuel	Dewpoint °C
0	0	11.85	10.792	1.025	59.1
0	40	11.85*	10.861*	2.094*	59.7
5	40	11.22	11.352	2.097	39.0
10	40	10.65	11.844	2.101	57.9
15	40	10.14	12.336	2.104	57.1
20	40	9.67	12.828	2.108	56.3
25	40	9.25	13.320	2.111	55.7
30	40	8.86	13.812	2.115	54.6
40	40	8.17	14.795	2.122	53.3
50	40	7.59	15.779	2.128	52.2
60	40	7.08	16.763	2.135	51.0
70	40	6.63	17.746	2.142	50.0
80	40	6.24	18.730	2.149	49.0
90	40	5.89	19.713	2.156	48.0
100	40	5.58	20.697	2.167	47.1

*Values obtained from Table I.

NOTES:

A plot of the above values of excess air versus dew-point temperature appears in Figure I.

CC&S MICROGRAPH
G8-15
Two Millimeters, Centimeteters lines heavy
MADE IN CANADA

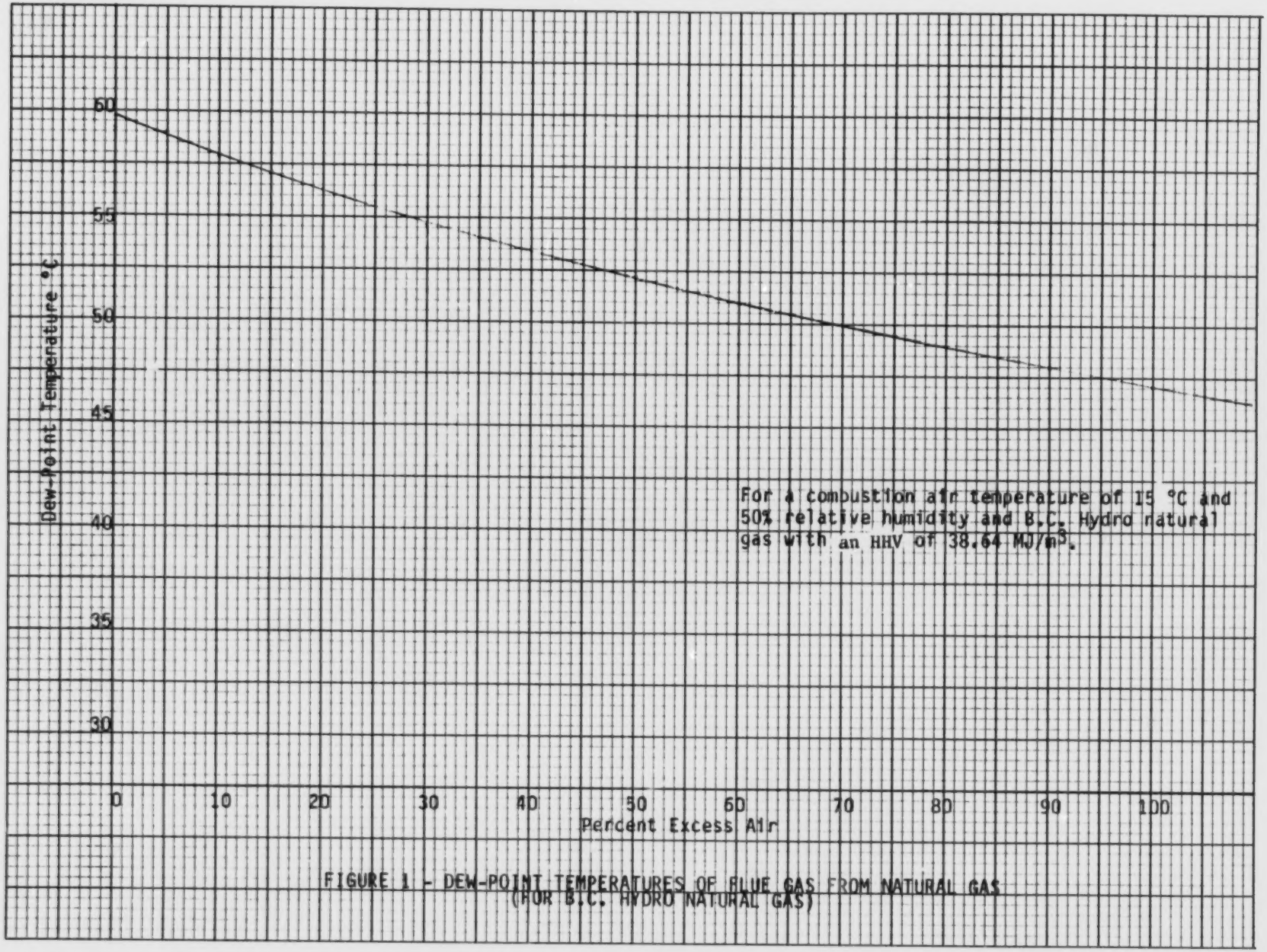


FIGURE 1 - DEW-POINT TEMPERATURES OF FLUE GAS FROM NATURAL GAS (FOR B.C. HYDRO NATURAL GAS)

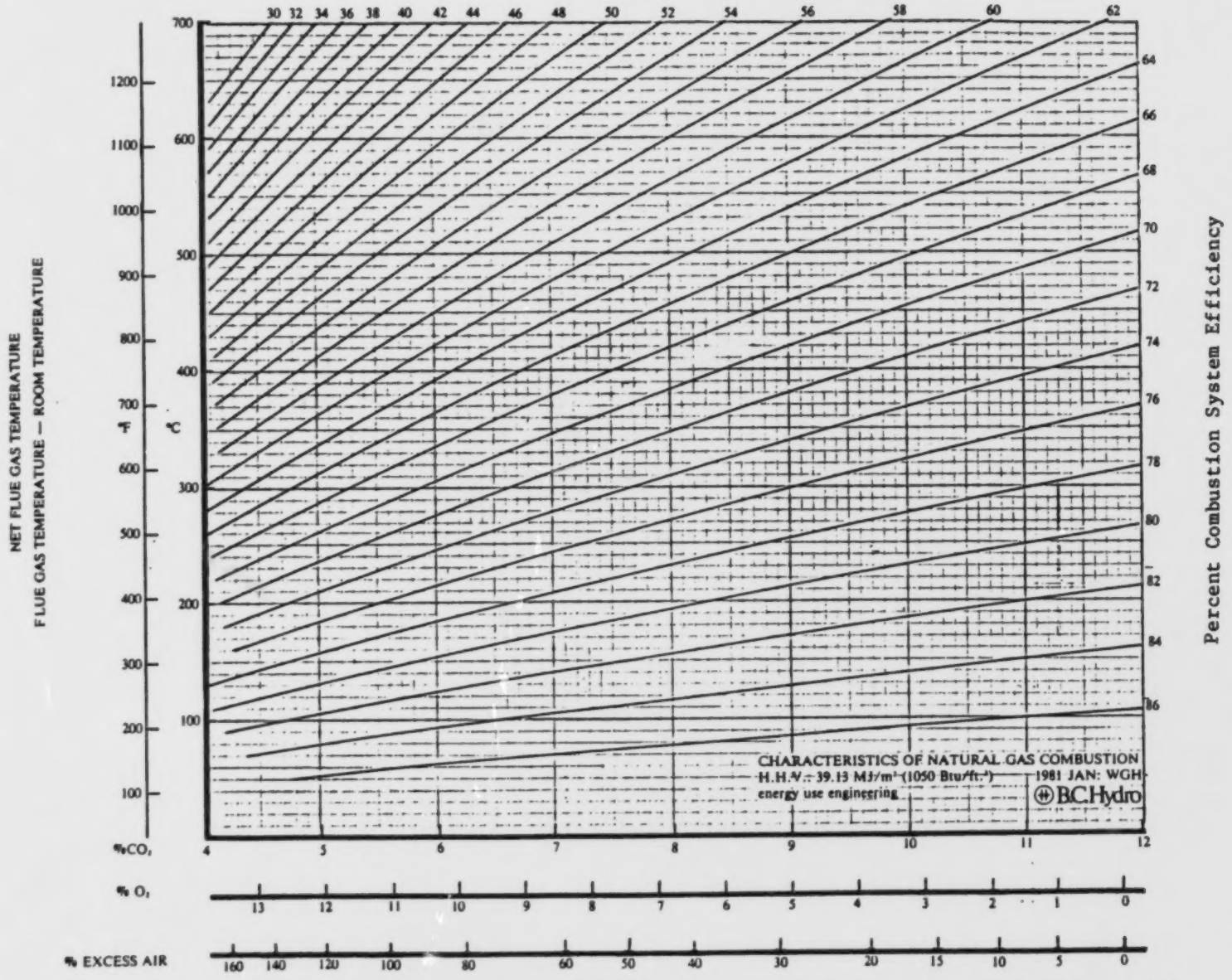


FIGURE 2 - CHARACTERISTICS OF NATURAL GAS COMBUSTION (FOR B.C. HYDRO NATURAL GAS)

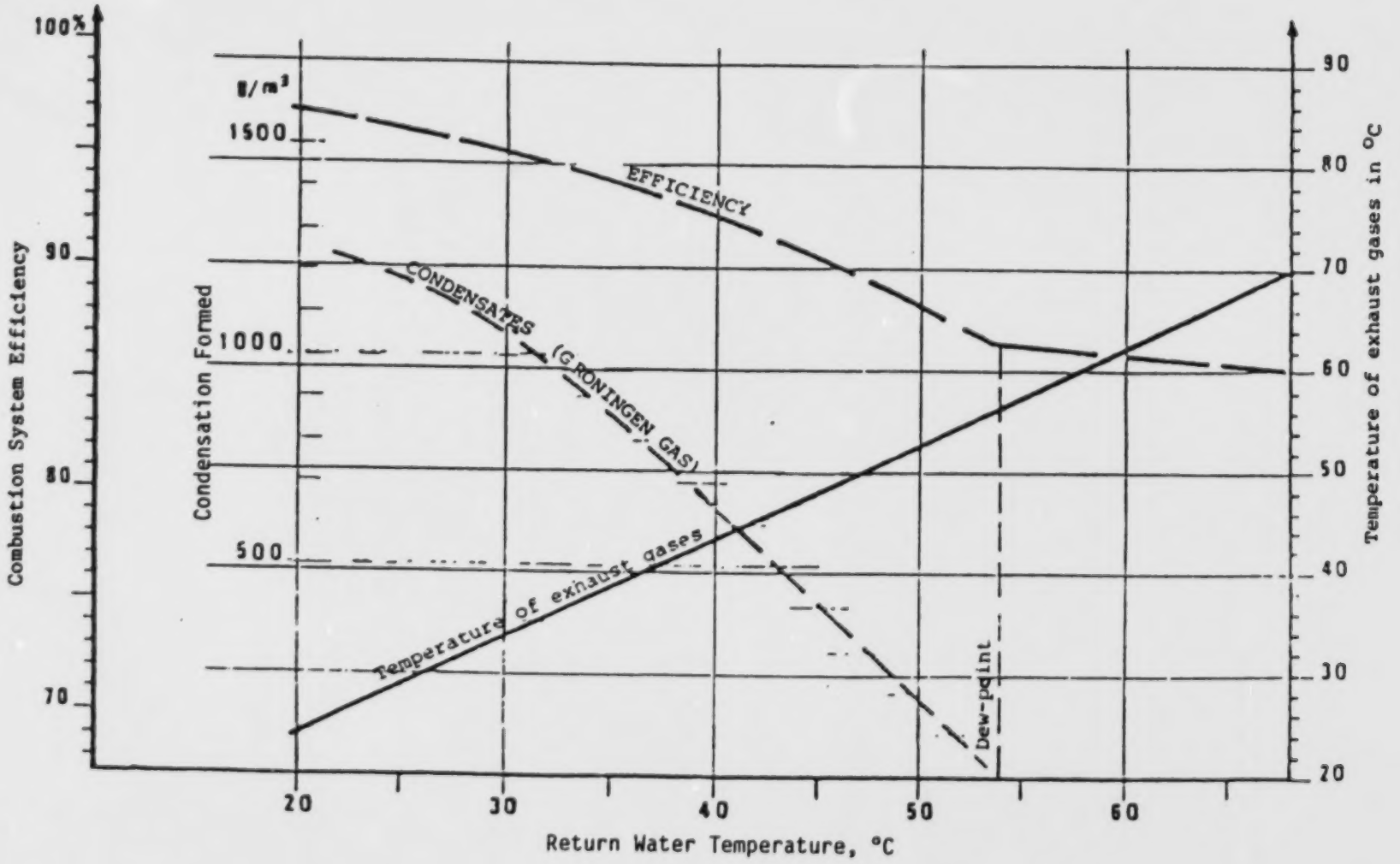


FIGURE 3 - TYPICAL RELATIONSHIP BETWEEN BOILER COMBUSTION SYSTEM EEFFICIENCY AND RETURN WATER TEMPERATURE

2.6.2 Condenser Types

Heat exchangers used to condense vapours by removing their latent heats are called condensers. The latent heat is removed by absorbing it in a cooler liquid called the coolant. There are two classes of condensers:

1. Surface Condensers.

In surface or indirect condensers, the condensing vapour and coolant are separated by a tubular heat-transfer surface. The vapour is usually admitted to the shell and is condensed on the outside of the tubes.

Surface flue gas condensers are basically of two types in terms of construction. The first, referred to as a gas-tube condenser, is constructed like a fire-tube boiler with gas flow in the tubes. In the second type, referred to as a water-tube condenser, the coolant flows inside tubes with exterior fins exposed to the flue gas to increase the gas-side heat transfer coefficient since it is much smaller than the liquid side coefficient. As a result, water-tube condensers can be built physically smaller than the gas-tube condensers, which can be an advantage in retrofit applications with space limitations. Gas-tube condensers have an advantage over water-tube condensers of the same materials where the gas-side surface needs to be coated for corrosion protection because fins cannot be satisfactorily coated. Gas-tube condensers of all aluminum construction, where no lining of the interior of the tubes is necessary, can be built with longitudinal fins inside the tubes. Such tubes are usually aluminum extrusions.

Typical water heating circuits possible with surface flue gas condensers are illustrated in Appendix D.

2. Direct-Contact Condensers

In the majority of applications of direct-contact condensers, the coolant and vapour streams, both of which are usually water, are physically mixed, and leave the condenser as a single stream. The quantity of non-condensible gases in the vapour stream is relatively

FLUE GAS NET TEMPERATURE °C

CO_2	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	% Excess Air
11.5	12.4	12.8	13.2	13.6	14.0	14.4	14.8	15.2	15.6	16.0	16.4	16.8	17.2	17.6	18.0	18.4	2.73
11.0	12.5	12.9	13.3	13.7	14.1	14.5	15.0	15.4	15.8	16.2	16.6	17.0	17.4	17.8	18.3	18.7	6.93
10.5	12.6	13.0	13.4	13.8	14.3	14.7	15.1	15.5	16.0	16.4	16.8	17.2	17.7	18.1	18.5	18.9	11.54
10.0	12.6	13.1	13.5	14.0	14.4	14.8	15.3	15.7	16.2	16.6	17.0	17.5	17.9	18.4	18.8	19.2	16.60
9.0	12.8	13.3	13.8	14.3	14.7	15.2	15.7	16.2	16.6	17.1	17.6	18.1.	18.5	19.0	19.5	19.9	28.40
8.0	13.1	13.6	14.1	14.6	15.2	15.7	16.2	16.7	17.2	17.7	18.3	18.8	19.3	19.8	20.3	20.8	43.20
7.0	13.4	14.0	14.6	15.1	15.7	16.3	16.8	17.4	18.0	18.5	19.1	19.7	20.3	20.8	21.4	22.0	62.14

FLUE GAS NET TEMPERATURE °C

CO_2	220	230	240	250	260	270	280	290	300	350	400	450	500	550	600	650	% Excess Air
11.5	18.8	19.2	19.6	20.0	20.4	20.8	21.2	21.6	22.0	24.0	26.0	28.1	30.2	32.3	34.4	36.6	2.73
11.0	19.1	19.5	19.9	20.3	20.7	21.2	21.6	22.0	22.4	24.4	26.6	28.8	30.9	33.1	35.4	37.6	6.93
10.5	19.4	19.8	20.2	20.6	21.2	21.5	21.9	22.3	22.8	24.9	27.3	29.5	31.8	34.0	36.4	38.7	11.54
10.0	19.7	20.1	20.6	21.0	21.4	21.9	22.3	22.8	23.2	25.4	28.0	30.3	32.7	35.1	37.5	39.9	16.60
9.0	20.4	20.9	21.4	21.8	22.3	22.8	23.3	23.7	24.2	26.6	29.7	32.2	34.8	37.4	40.0	42.7	28.40
8.0	21.3	21.9	22.4	22.9	23.4	23.9	24.4	25.0	25.5	28.1	31.8	34.6	37.4	40.3	43.2	46.2	43.20
7.0	22.5	23.1	23.7	24.2	24.8	25.4	26.0	26.4	27.1	29.9	34.5	37.7	40.9	44.1	47.4	50.7	62.19

TABLE III - STACK LOSSES WITHOUT FLUE GAS CONDENSATION

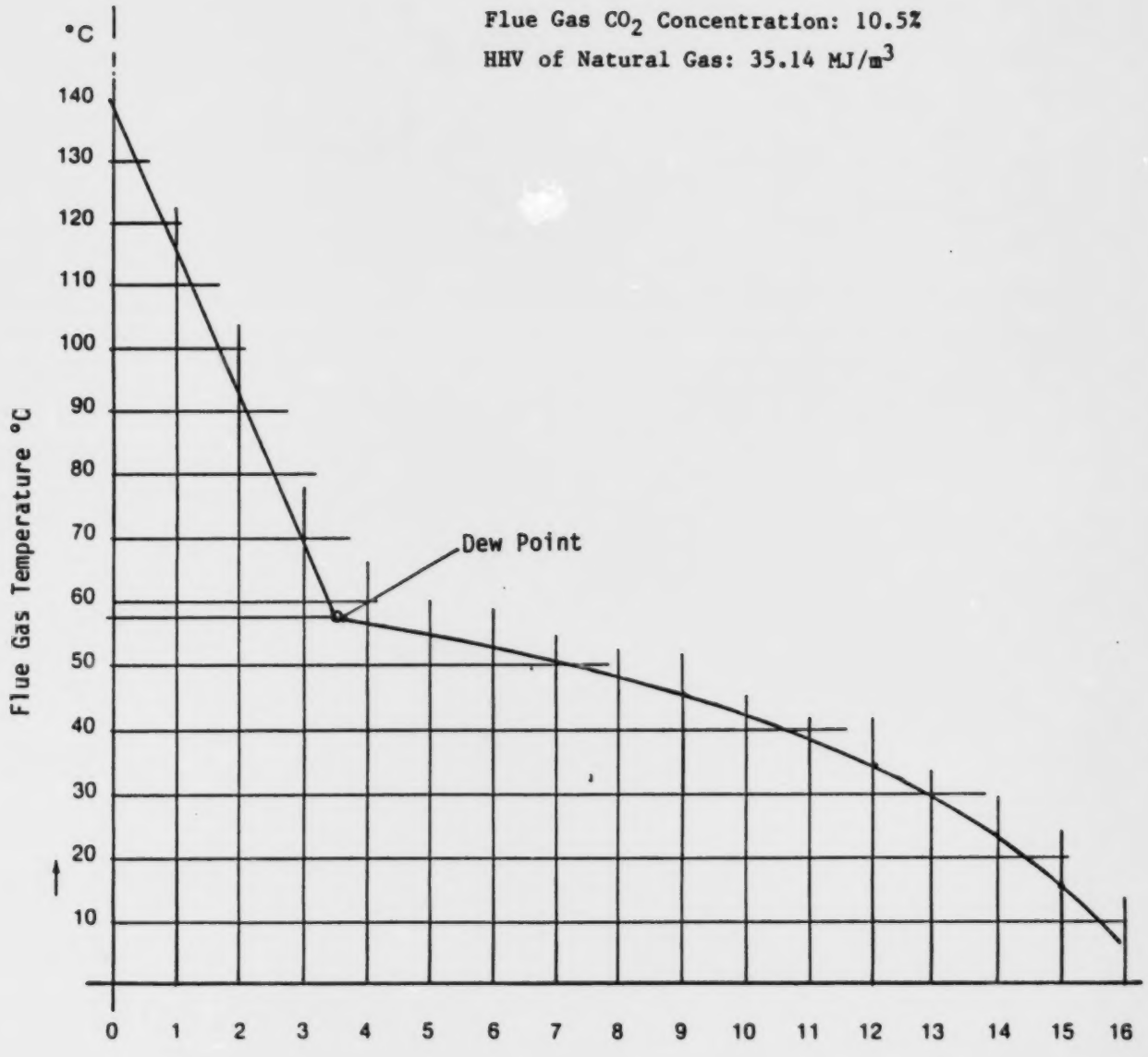


FIGURE 4 - TYPICAL RELATIONSHIP BETWEEN FLUE GAS TEMPERATURE AND HEAT RECOVERED BY FLUE GAS CONDENSER

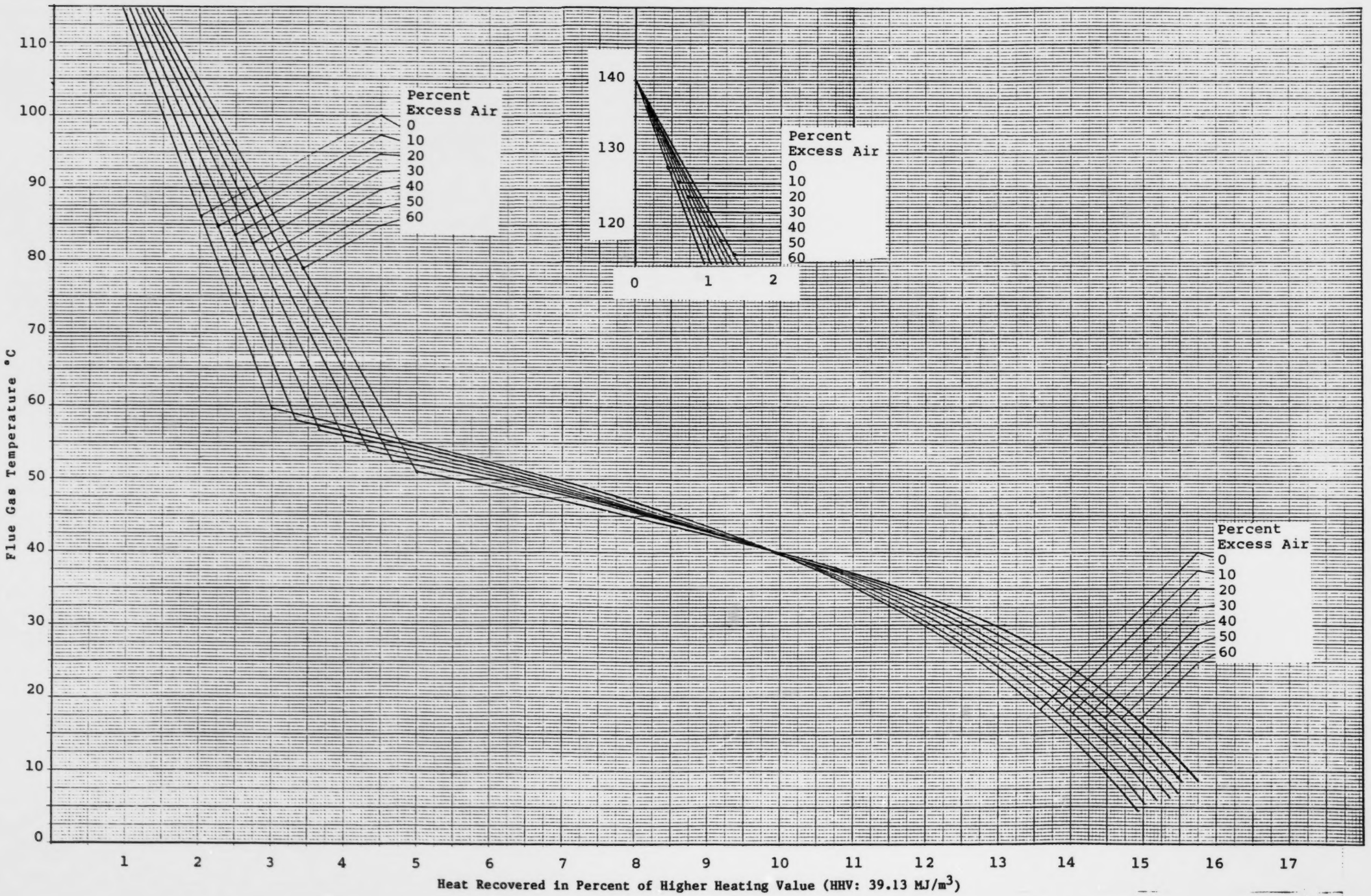


FIGURE 5 - RELATIONSHIP BETWEEN FLUE GAS TEMPERATURE, EXCESS AIR AND HEAT RECOVERED BY FLUE GAS CONDENSER

low. Typical common examples, but which are not used for flue gas condensation, are the countercurrent barometric condenser and the concurrent ejector-jet barometric condenser.

Direct-contact heat exchangers applicable to flue gas condensation in which the quantity of non-condensible gases relative to the quantity of vapour is high are:

- baffle-tray columns
- spray chambers
- Packed columns

An illustrative direct-contact condensation heat recovery process flow diagram is shown in Figure 6.

Although flue gas condensers are quite commonly used in Europe, there have been few applications in North America. These have been mainly restricted to the direct-contact type in fairly large-scale applications. In Europe the use of surface condensers appears to be more prominent, including boilers in the smaller size ranges. Surface flue condensers are extensively used in greenhouses in Holland where low-temperature water can be used for soil and crop heating. In such applications an added benefit results from the cooling of flue gases in that the flue gases with their carbon dioxide content can be used as an enriched atmosphere for greenhouse crops or plants.

It should be pointed out that the so-called flue gas condenser is not a condenser in the strict sense since it also recovers sensible heat from non-condensible gases which comprise the bulk of the volume of gases and vapours entering the condenser. A more appropriate term would be a "flue gas condensing heat exchanger", which more correctly reflects its function. However, use of the term "flue gas condenser" is well established and hence adopted in this study.

2.6.3 Condenser Efficiency

The efficiency of a condenser is defined by the following formula,

$$\frac{T_{in} - T_{out}}{T_{in} - t_{in}} \times 100\%$$

where,

T in = flue gas inlet temperature
T out = flue gas outlet temperature
t in = water inlet temperature

For given flue gas and water inlet temperatures, the lower the flue gas outlet temperature the higher will be the condenser efficiency.

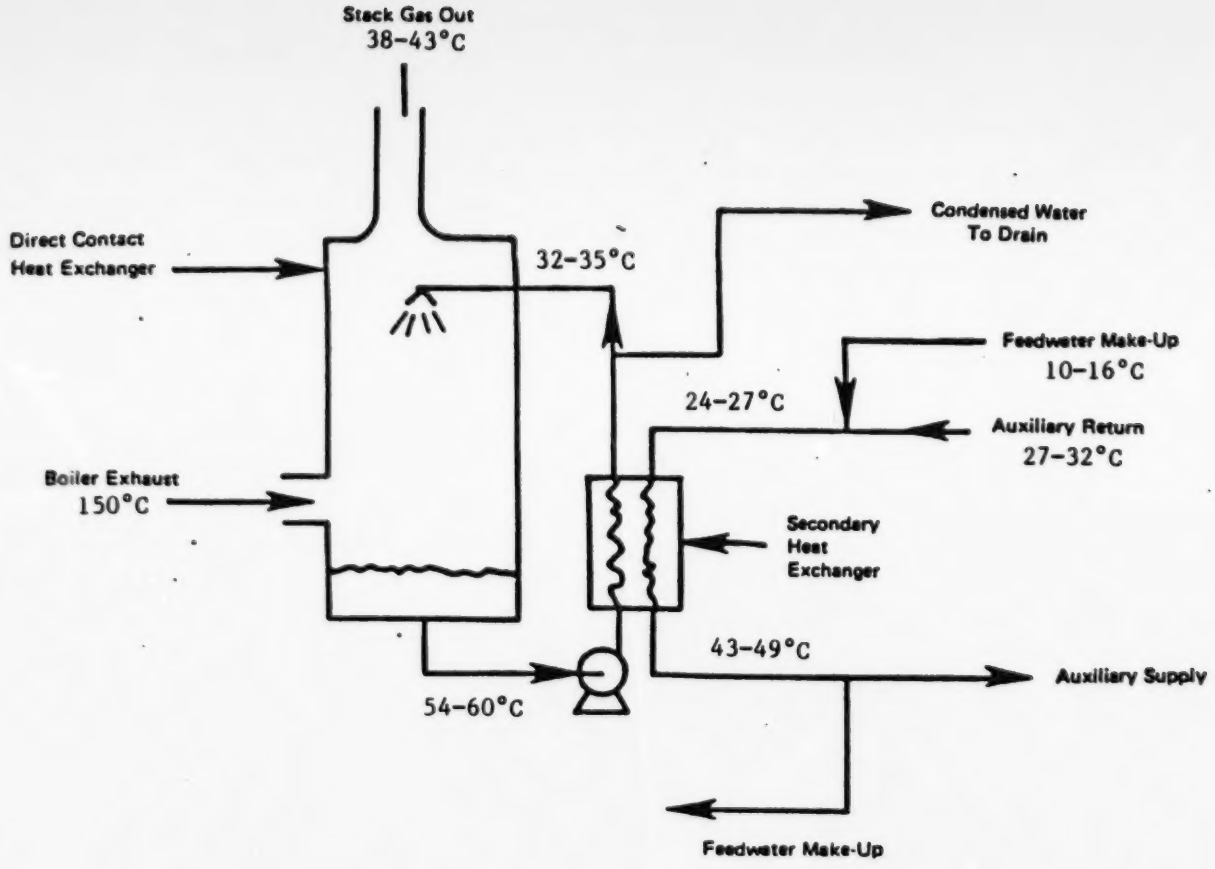


FIGURE 6 - TYPICAL DIRECT CONDENSATION HEAT RECOVERY SYSTEM FLOW DIAGRAM

3.0 EVALUATION OF EXISTING FLUE GAS CONDENSATION INSTALLATIONS

3.1 INTRODUCTION

Recent installations (1983-84) of surface flue gas condensers at two greenhouse operation sites in the B.C. Lower Mainland and a direct contact flue gas condenser at the Canada Packers Inc. plant in Winnipeg, Manitoba, were studied.

Surface condensers at the two B.C. Lower Mainland sites, Site No. 1 and Site No. 2, are imported from Holland and provide examples of gas-tube and water-tube surface condensers. In both cases, because of the increased pressure drop imposed by the flue gas condenser in the flue, the boiler could not be operated at rated capacity. For the boilers to achieve rated capacities with the flue gas condensers, the pressure head capacities of the forced-draft fans will have to be increased or induced-draft fans installed on the condenser flue gas outlets. However, the decrease in boiler rated capacity is largely offset by the increase in system efficiency by the flue gas condenser. Packaged boilers manufactured in Holland are evidently not experiencing this problem, apparently because they have more efficient fans and burners. Condensers for the Canadian market should be designed, where feasible, with lower flue gas pressure losses than those for the Dutch market.

B.C. Hydro and Power Authority, Energy Conservation Division, carried out evaluations of the condenser retrofitted boilers at the two Lower Mainland sites in 1984. A copy of their report for Site No. 1, in Langley, B.C., is found in Appendix A and their report for Site No. 2 in Pitt Meadows, B.C., is found in Appendix B. In the two reports, fuel savings are incorrectly calculated indicating fuel savings which are too high. This results from the use of "original efficiency" instead of "new efficiency" in the denominator of the formula for calculating fuel savings, which is,

$$\frac{\text{Improvement in efficiency}}{\text{New efficiency}} \times 100\%$$

Results of the tests, with corrected fuel savings values are summarized in Table IV.

The direct-contact flue gas condensation heat recovery system at the Canada Packers Inc. plant in Winnipeg, Site No. 3, was implemented with assistance from the Manitoba/Canada Conservation and Renewable Energy Demonstration Program. Performance and economic data provided in the Program report are summarized below.

Previous combustion efficiency of boilers	81.8%
Combustion efficiency of boilers with flue gas condensation heat recovery	92.2%
Heat recovery efficiency (Average)	70%
Capital cost (1982)	$400,300
Annual net fuel savings	$141,000/yr.
Simple payback period	2.8 yr.

3.2 SITE NO. 1

3.2.1 Description of Boiler and Condenser

The Saskatoon fire-tube hot water boiler of 162,800 MJ/hr. (4,372,000 Btu/hr) maximum input capacity is retrofitted with a Zontingh Aalsmeer Type 21 Total Eco Vario Combi water-tube flue gas condensing heat exchanger of Dutch manufacture. The words "Total Eco Vario Combi" denote "a two-coil section total economiser." A two-coil section is used where the low-temperature heating load, such as soil heating, is insufficient to remove all of the available heat from the flue gases. An additional coil section is then incorporated in the heat exchanger, utilizing a higher-temperature water circuit for purposes such as space heating. See illustrations in Appendix A.

TABLE IV - SUMMARY OF PERFORMANCE TEST RESULTS FOR TWO EXISTING FLUE GAS CONDENSER EQUIPPED BOILERS BY B.C. HYDRO - SITE NO. 1 AND SITE NO. 2

Item	Site No. 1, Langley, B.C.		Site No. 2, Pitt Meadows, B.C.	
	Low Fire	Medium Fire	Low Fire	High Fire
Flue Gas Leaving Boiler				
CO_2 concentration (dry), %	5	7	6	7.5
Excess air, %	122.2	61.8	86.9	51.7
Temperature, °C (°F)	125 (257)	150 (302)	84 (183)	100 (212)
Flue Gas Leaving Condenser				
Temperature, °C (°F)	36 (96.8)	43.5 (110.3)	29 (84)	31 (88)
Water temperature rise °C (°F) across condenser	10 (18)			9 (16)
Boiler shell loss, % of input	5.8	2.9	3.2	1.2
Boiler flue loss, % of input	18.1	17.5	15.4	15.3
Recuperator stack loss, % of input	7.4	8.0	4.9	4.9
Boiler efficiency before condenser, %	76.1	79.6	81.4	83.5
Boiler efficiency after condenser, %	86.8	89.1	91.9	93.9
Condenser heat recovery, % of input	10.7	9.5	10.5	10.4
Fuel savings, %	12.3	10.7	11.4	11.1
The following are for purposes of comparison only:				
Comb. system eff. from above data, % of input	92.6	92.0	95.1	95.1
Comb. system eff. from Fig. 2 and Fig. 5, % of input		91.5		95.7

Notes:

(1) Rated boiler input of hot water boilers: Site No. 1 - 4,372,000 Btu/hr.
Site No. 2 - 14,650,000 Btu/hr.

(2) HHV of natural gas: Site No. 1 - 38.9 MJ/m3 (1,045 Btu/m3)
Site No. 2 - 39.35 MJ/m3 (1,057 Btu/ft3)

The condenser heat absorption coils are copper tubing expanded into aluminum alloy fins which apparently also protect the copper against corrosion. The housing or shell is specified as Corten steel, which is a low-alloy high-strength steel with fractional percentage of copper, nickel and chromium but to which no particular corrosion-resistant properties could be attributed. The shell was examined in the fall of 1985 and was reported to be corroding. Examination of the coils was not possible since it would entail removal of the stack. The owner intends to remove the stack for examination of the coils in the fall of 1986.

3.2.2 Evaluation of System Performance

A comprehensive evaluation of this flue gas condensation system is found in Appendix A and a summary of results in Table IV.

The following are results of a random test of the system made during actual operation.

Measured data:

Flue gas net temperature leaving boiler	150°C
Flue gas temperature leaving condenser	50°C
Flue gas oxygen concentration (dry)	5.8%
Room temperature	18°C

Calculated data:

Excess air	34.3%
Combustion system efficiency (Without condenser - from Fig. 2)	82.5%
Combustion system efficiency (With condenser - from Fig. 2 and Fig. 5)	90.4%
Indicated fuel saving	8.6%

3.3 SITE NO. 2

3.3.1 Description of Boiler and Condenser

The boiler at this site is a relatively new Cleaver-Brooks fire-tube hot water boiler with a rated input of 545,400 MJ/hr. (14,650,000 Btu/hr.). The condensing heat exchanger is a Dalsem Type C400 gas-tube flue gas condensing heat exchanger manufactured in Holland. See illustrations in Appendix B. The cooled flue gases are used as a source of carbon dioxide for greenhouse crops. This has proved to be so beneficial that the boiler is operated at times specifically for carbon dioxide generation.

The condenser shell and end plates are of Corten steel. Steel 37 is specified for the tube plates and flue gas duct. Tubes are 1-1/4" welded steel "gas pipe". All surfaces in contact with the flue gas are coated with coal tar epoxy. No sign of corrosion was reported when the interior of the condenser was examined in the summer of 1985 after about one-year's service.

3.3.2 Evaluation of System Performance

The following are results of a random test of system made during actual operation.

Measured data:

Flue gas net temperature leaving boiler	105°C
Flue gas temperature leaving condenser	35°C
Flue gas oxygen concentration	3.7%
Room temperature	18°C

Calculated data:

Excess air	19.8°C
Combustion system efficiency (Without condenser - from Fig. 2)	85.5%
Combustion system efficiency (With condenser - from Fig. 2 and Fig. 5)	96.5%
Indicated fuel saving	10.3%

3.4 SITE NO. 3

3.4.1 Description of Direct Contact Flue Gas Condensation System

This system at the Canada Packers Inc. plant in Winnipeg was supplied by John Thurley Ltd., England. A flow diagram of the system and equipment photographs are found in Appendix C. The John Thurley system is similar to that marketed by Rocket Research Company, described in Appendix E. Heat is recovered from the flue gases by bringing them into direct contact with cold water sprays whereby the gases are cooled to about 38°C, their water vapour partially condensed, and the water heated to about 54°C. The water used to cool the flue gases is recirculated through a surface heat exchanger in which it gives up its heat to water for consumptive or heating medium use. Water in the primary circuit, i.e., water used for direct contact cooling in the condenser, may, in some instances, be used directly, such as for floor washing, where a low level of acidity and impurities can be tolerated. Water in the secondary circuit leaves the exchanger at about 49°C; it is then further heated with steam for plant process, sanitation and boiler make-up use.

Water recirculating pumps supplied with the original equipment were of cast iron construction. These were damaged by corrosion by the acidic cooling water and had to be replaced by stainless steel pumps after four months of operation.

3.4.2 Process Conditions

The following process conditions were noted from a random observation.

Flue gas temperature entering condenser	150°C
Flue gas temperature leaving condenser	35°C
Primary water circuit temperatures:	
Entering condenser from heat exchanger	35°C
Leaving condenser to heat exchanger	44°C
Secondary water circuit temperatures:	
Entering heat exchanger	27°C
Leaving heat exchanger	41°C

4.0 POTENTIAL FOR FLUE GAS CONDENSATION HEAT RECOVERY AT STUDY PLANT

4.1 DESCRIPTION OF PLANT

The study plant, J & L Meats Company Ltd., located in Surrey, B.C., is a beef slaughtering and packing plant which has experienced considerable growth and expansion of plant over the last ten or so years. As the plant was built in a number of stages to meet production requirements, the locations of steam and hot water generating units were not centralized. This is a disadvantage from points of view of any possible sharing of common component, interconnection, and operation and maintenance. Before any further sizable plant expansion is undertaken a rationalization of steam, hot water and refrigeration services would be in order.

Photographs of the plant appear in Figure 7. The plant operates round-the-clock but the last shift of the day is usually devoted largely to clean-up.

Steam and hot water natural-gas-fired generating units comprise the following:

Steam

1. Cleaver-Brookes Model CBH700-30, 150 psig fire-tube steam boiler with a rated input of 1.324 MJ/hr. (1,255,000 Btu/hr.)

2. Volcano Model 5B-25C-C7 150 psig fire-tube steam boiler with a rated input of 1,108 MJ/hr. (1,050,000 Btu/hr.)

Hot Water

1. Superhot Model AA-3000M atmospheric hot water boiler with a rated input of 3,165 MJ/hr. (3,000,000 Btu/hr.)

2. Two Jetglass Model M65-60-J1B-3N hot water boilers each with a rated input of 753 MJ/hr. (714,000 Btu/hr.)

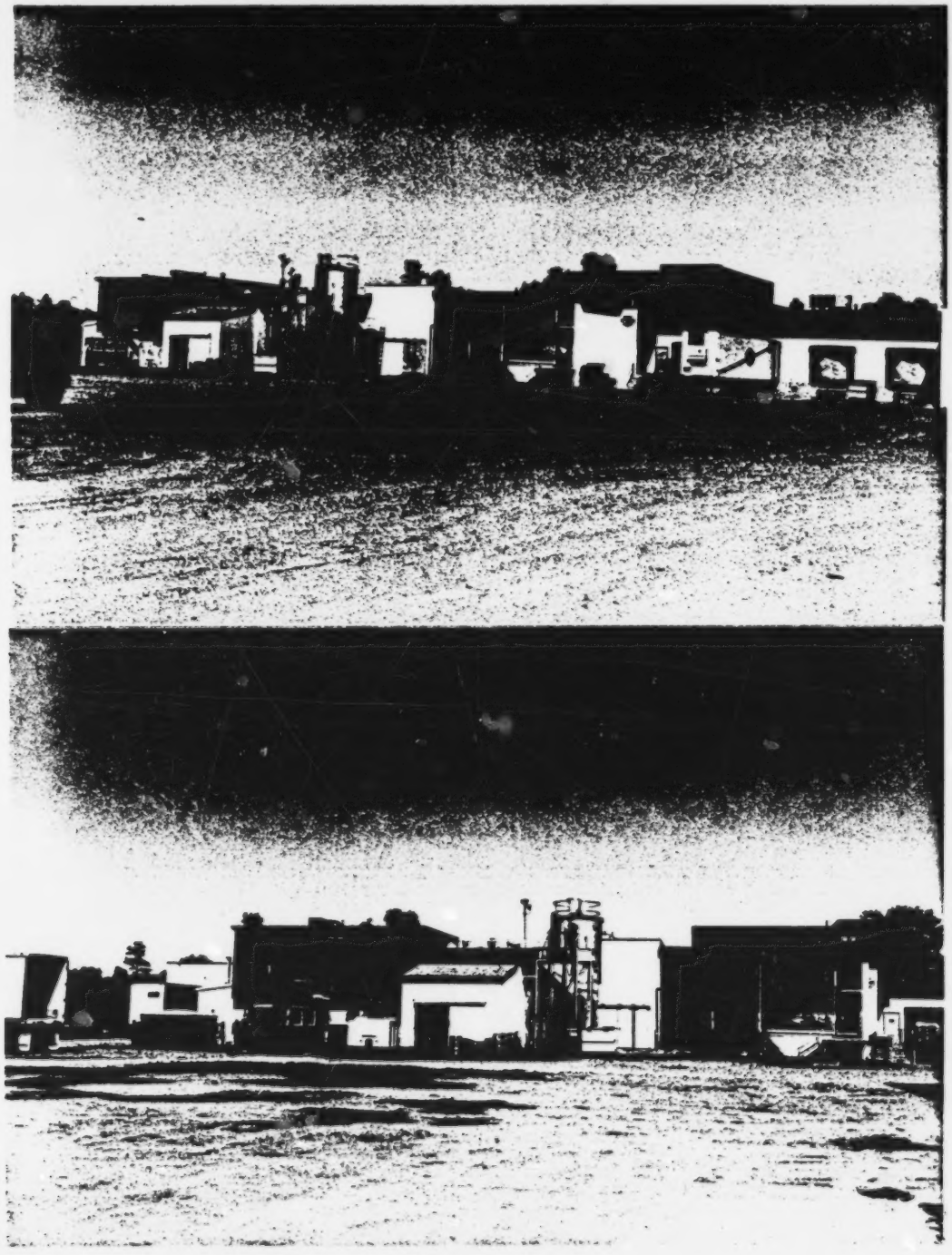


FIGURE 7 - PLANT PHOTOGRAPHS -- J & L MEATS CO. LTD.

The two steam boilers are located near enough to one another for possible use of a common flue gas heat recovery system. The two Jetglass hot water boilers are remote from one another and from the Superhot boiler, but they are too small for practical application of flue gas heat recovery. All boilers operate on on/off cycle with the on-cycle at boiler rated capacity.

A flow diagram of steam and hot water services is shown in Figure 8. Note that the hot water heating system is rather unconventional in that there is no isolated intermediate closed hot water heating medium circuit. Service hot water is heated by passing directly through the Superhot hot water boiler after it is mixed with sterilizer heating water. Such practice could, depending on water quality, accelerate corrosion of boiler tubes. The possible use of one hot water heating boiler with a conventional hot water heating circuit should be considered in any future rebuild of the hot water heating system. Hot water is utilized for plant washdown and the heating of sterilizers. Steam is used primarily for shrink-wrapping with the balance of use for fat cooking and heating of the fat storage tank. There is no steam condensate return to the boilers; hence all of the boiler feedwater is fresh makeup water. No condensate return from shrink-wrapping is possible because steam is consumed directly in the process. Difficulty of collection and the availability of high-quality boiler make-up water discourage condensate return from fat cooking and fat storage tank heating.

4.2 WATER AND NATURAL GAS CONSUMPTION

Recent records of water and natural gas usages are shown in Table V and Table VI respectively. The last plant expansion was completed in early 1985. Therefore, only water and natural gas use figures for mid and late 1985 are considered representative.

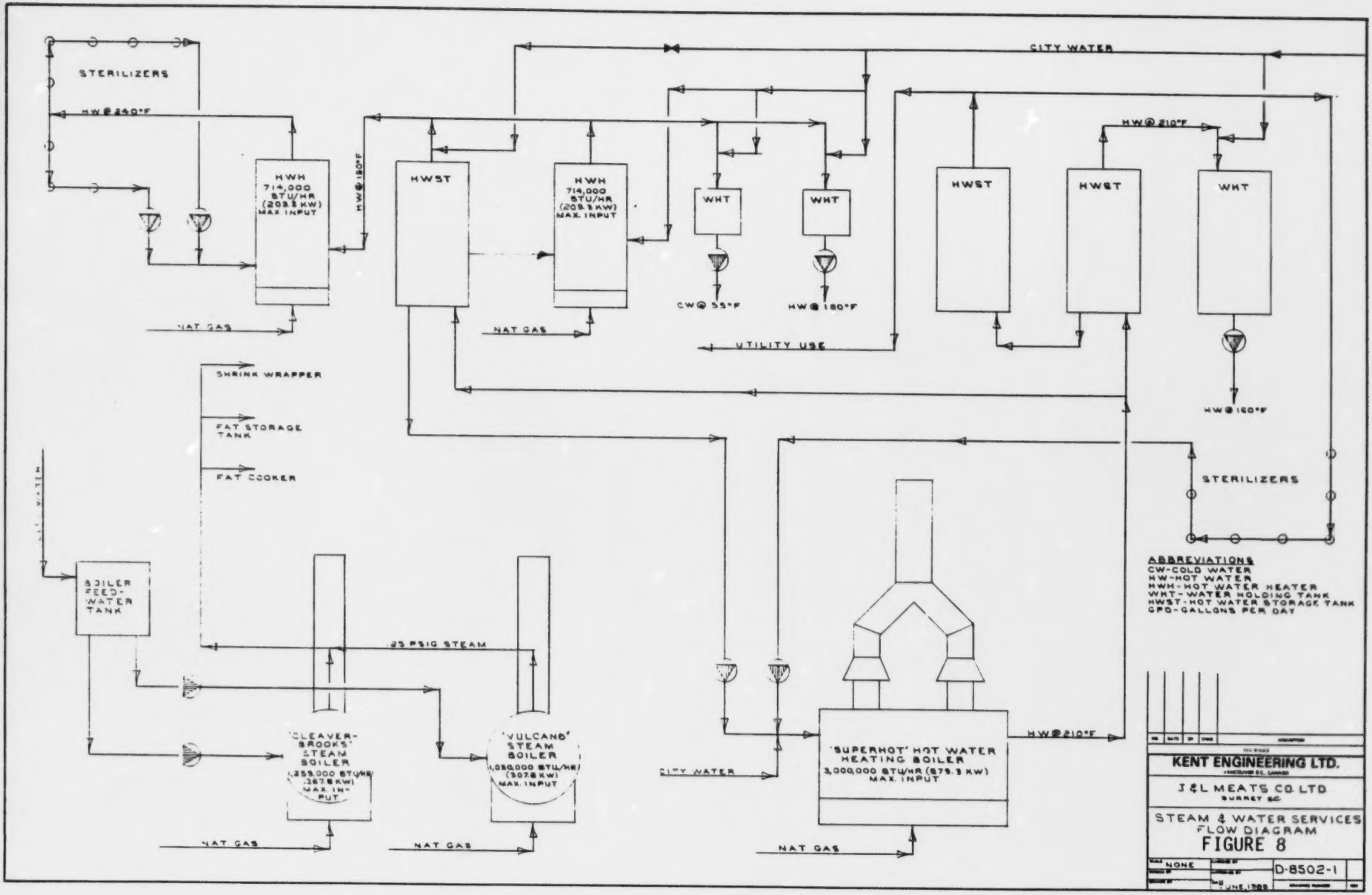

STERILIZERS
HW@240°F
HWH
714,000
BTU/HR
(209.3 KW)
MAX. INPUT
HW@180°F
HWST
NAT GAS
HWH
714,000
BTU/HR
(209.3 KW)
MAX. INPUT
NAT GAS
WHT
CW@55°F
WHT
HW@180°F
CITY WATER
UTILITY USE
HWST
HWST
HW@210°F
WHT
HW@160°F
STERILIZERS
SHRINK WRAPPER
FAT STORAGE TANK
FAT COOKER
CITY WATER
BOILER FEED-WATER TANK
23 PSIG STEAM
'CLEAVER-BROOKS' STEAM BOILER
(255,000 BTU/HR (367.8 KW) MAX. INPUT
NAT GAS
'VULCANO' STEAM BOILER
(1,050,000 BTU/HR (307.8 KW) MAX. INPUT
NAT GAS
CITY WATER
'SUPERHOT' HOT WATER HEATING BOILER
3,000,000 BTU/HR (879.3 KW) MAX. INPUT
NAT GAS
HW@210°F
ABBREVIATIONS
CW-COLD WATER
HW-HOT WATER
HWH-HOT WATER HEATER
WHT-WATER HOLDING TANK
HWST-HOT WATER STORAGE TANK
GPD-GALLONS PER DAY
KENT ENGINEERING LTD.
J&L MEATS CO. LTD
SURREY B.C.
STEAM & WATER SERVICES
FLOW DIAGRAM
FIGURE 8
SCALE NONE
DRAWN BY
CHECKED BY
APPROVED BY
DATE JUNE, 1988
D-8502-1

TABLE V - WATER CONSUMPTION RECORD

Period	Consumption		
	gpd (U.S.)	gpd (Imp.)	m^3/day
Oct. 1/84-Dec. 31/84	28,648	23,873	108.43
Jan. 1/85-Mar. 31/85	40,061	33,384	151.63
Apr. 1/85-June 30/85	28,592	18,829	85.51
July 1/85-Sept. 30/85	39,338	32,782	148.89
Sept. 30/85-Dec. 31/85			

TABLE VI - NATURAL GAS CONSUMPTION RECORD

ACT-21 8506 32631 WORKDAY 12 TYPE-CURRENT PREM-500 SIC-6140
NAM-J AND L MEAT CO RESP-01JUL74
ADR-17565 65A AVE READ-MONTHLY

TO	DAYS	CONS	TAX	AMT	CHGECODE	BILLCODE	RATE
1-17MAY/85	31	1,588.6	460.70	6,581.44	REGULAR	VER RDG	2208
2-16APR	32	1,516.7	439.86	6,283.78	REGULAR	NORMAL	
3-15MAR	31	1,641.6	476.06	6,800.86	REGULAR	NORMAL	
4-12FEB	29	1,458.7	423.06	6,043.66	REGULAR	NORMAL	
5-14JAN	34	1,598.8	463.66	6,623.67	REGULAR	NORMAL	
6-11DEC	28	1,408.1	408.39	5,834.17	REGULAR	NORMAL	
7-13NOV	32	1,439.5	417.49	5,964.17	REGULAR	NORMAL	
8-12OCT	28	1,120.1	324.93	4,641.85	REGULAR	NORMAL	
9-14SEP	31	1,066.5	309.40	4,419.95	REGULAR	NORMAL	
10-14AUG	32	1,029.4	294.76	4,210.78	REGULAR	NORMAL	
11-13JUL	31	1,061.7	301.25	4,303.54	REGULAR	NORMAL	
12-12JUN/84	29	986.7	279.99	3,999.85	REGULAR	NORMAL	

June 20 to Aug. 20, 1985	2,913.9
Aug. 20 to Sept. 20, 1985	1,549.2
Sept. 20 to Oct. 20, 1985	1,511.6
Oct. 20 to Nov. 20, 1985	1,332.6
Nov. 20 to Dec. 20, 1985	1,612.4

An elapsed-time meter was connected across the gas valve on the Superhot hot water heating boiler for a period of 15 days. The recorded on-time for the period was 127 hours. Since the boiler operates on on/off cycle and has a rated input of 3,165 MJ/hr. (3,000,000 BTU/hr.) the total input to the boiler in the period was 127 hr. x 3,165 MJ/hr. = 402,000 MJ (381,000,000 Btu). Assuming an average city water temperature of 7°C (45°F), a boiler efficiency of 80 percent, and an average hot water supply temperature of 82°C (180°F), the daily output volume of hot water is,

$$\frac{402{,}000 \times 238.9 \times 0.80}{1{,}000 \times (82-7) \times 15} = 68.29 \text{ m}^3\text{/day (18,041 gpd)}$$

The 30-day natural gas consumption is about 1,550,000 ft^3 (see Table VI) of which about

$$\frac{381{,}000{,}000 \times 2}{1{,}555{,}000 \times 1{,}038} \times 100\% = 47.4\%$$

is consumed by the Superhot hot water heating boiler. An additional 30 percent hot water is judged to be generated by all other hot water generating units, including miscellaneous hot water tanks. The balance of natural gas usage is attributed to steam generation. Using the above figures and water and natural gas consumption records in Table V and Table VI an estimate of consumptive distribution for water and natural gas was prepared as shown in Table VII.

4.3 BOILER EFFICIENCY TESTS

Combustion system efficiencies of the boilers were determined with a Kane-May flue gas analyzer. The results are tabulated below.

Item	Cleaver-Brooks	Volcano	Superhot
Oxygen conc., %	1.6	3.0	8.2
CO conc., ppm	200	0	0
Net temp. °C (°F) (Ambient temp. 6°C)	198 (356)	216 (389)	204 (367)
Excess air, %	7.4	15.0	57.6
Combustion system eff., % (From Figure 2)	82.0	80.9	78.5
Flue gas dew point temp., °C (From Figure 1)	58.4	57.0	51.2

The above tests performed on November 18, 1985, are the last in a series performed in 1985 and were taken after tune-up of the Cleaver-Brooks boiler (by the supplier) and some retubing of the Volcano boiler. Note the depression of flue gas dew point temperature with increasing levels of excess air. Since the boilers operate on on/off cycle the above tests are at maximum boiler loads. Combustion system efficiencies were obtained from Figure 2 and flue gas dew point temperatures from Figure 1.

TABLE VII - CONSUMPTIVE DISTRIBUTION OF WATER AND NATURAL GAS

Category	Consumption					
	Water			Natural Gas		
	Percent	m^3/day	(gpd)	Percent	MJ/day	(MBtu/day)
Hot Water Supply						
Superhot hot water heating boiler	50.1	68.29	(18,040)	47.4	26,800	(25.4)
Other hot water heating appliance	15.0	20.49	(5,410)	14.2	8,020	(7.6)
Steam Generation						
Cleaver-Brooks and Volcano boilers	4.7	6.36	(1,690)	38.4	21,730	(20.6)
Cold Water Supply						
All uses	30.2	41.11	(10,860)			
TOTALS	100.0	136.28	(36,000)	100.0	56,550	(53.6)

5.0 EVALUATION OF FLUE GAS CONDENSATION HEAT RECOVERY SYSTEMS FOR STUDY PLANT

5.1 INTRODUCTION

There are few manufacturers of flue gas condensers in Canada and the U.S. One manufacturer of direct contact flue gas condensers was identified in the U.S.: Rocket Research Company of Seattle, Washington, manufacture a system under license from L'Industrielle de Chauffage of France. Their information bulletin is reproduced in Appendix E. Two manufacturers of surface flue gas condensers were identified: Condensing Heat Exchanger Corp. of Latham, New York, and Andersen 2000 Inc., of Peachtree City, Georgia. Both use Teflon covered tubes in their condensers which make for costly construction.

A number of Dutch manufacturers of surface flue gas condensers with extensive records of application in the greenhouse industry was identified, namely,

- Van Dijk Heating
- Thermeta b.v.
- Enalco b.v.
- W.K. Crone b.v.
- Zontingh Aalsmeer
- Dalsem Kassenbouw b.v.

Some illustrations of surface flue gas condensers manufactured by the above are shown in Appendix F. The illustrations include both water-tube and gas-tube types. Although, the water-tube condensers have the advantage of being physically smaller because of the use of finned surfaces on the gas side, they may be more susceptible to corrosion because the peripheral edges of the fins are subjected to higher temperatures and they cannot be coated.

A summary of characteristics of flue gas condensers proposed by Dutch manufacturers for the steam and not water boilers is included in Appendix F. The condensers are sized for a higher hot water flows than that of the study plant, but this does not affect price appreciably.

Flue gas condensers as available in North America were determined to be too costly, at least for the small installations being considered in this study. A Rocket Research Company system for the Superhot boiler, as estimated by the supplier, would cost about $66,000 installed. The Cleaver-Brooks boiler was considered to be too small for practical heat recovery with this type of system. Equipment of Dutch manufacture was selected for reasons of cost, the extensive applications experience of the manufacturers, suitability for small boilers, and the existence of two sites in the area of the study plant that already employ Dutch flue gas condensers.

The above-mentioned flue gas condensation systems of North American manufacture are suitable both for the more corrosive fuel oil flue gases and natural gas flue gases. The systems made in Holland are suitable only for flue gases from natural gas which are less corrosive. Apparently, the view in Holland is that flue gases from fuel oil are just too corrosive for practical every-day condensation heat recovery, both from standpoints of equipment construction requirements and costs, the lesser amount of latent heat recoverable in the case of fuel oil and the disposal problems of the acidic condensate.

A study by N.V. Nederlandse Gasunie of the inpact on municipal sewage systems of the disposal of natural gas flue gas condensate from residential heating boilers, was completed in about 1980.[1] It showed that there would be no adverse effects on sewer materials of construction or sewage treatment, primarily because of its low volume and neutralization by domestic wastewater. The study gives the mean chemical composition of natural gas flue gas condensate as follows:

---

(1) G.J. van Rossum, P.H.J. Bartholomew, J. Voogd and H.A. Flendrig, "Disposal of Flue Gas Condensate from High Efficiency Boilers - Examination of Effects on the Drain System and the Environment," N.V. Nederlandse Gasunie.

Component	Mean Conc., mg/l.	Range mg/l.
Chloride (Cl^-)	3	0-5
Sulphate (SO_4^-)	25	2-40
Nitrite (NO_2^-)	50	0-200
Nitrate (NO_3^-)	50	30-150
pH (in pH units)	4	4.3-3.7

The range of the composition of the flue gas condensate is stated to reflect roughly the influence of the following parameters:

- presence of any contaminants in the combustion air
- total sulphur content of the natural gas used
- type of burner and materials of construction of heat exchangers

The condensate was found to have a very low buffering capacity, that is, only a very small amount of base is required to neutralize it --5 mg NaOH to neutralize 1 litre of condensate.

A condensate with a chloride concentration can be particularly corrosive. Combustion air with concentrations of chlorinated hydrocarbons as found in beauty parlors and dry cleaning establishments is a potential chloride source and has been reported by some domestic and commercial hot water boiler manufacturers in Canada to cause corrosion of boiler primary heat exchange coils. In condensing boilers, under such conditions, corrosion of the condensers can also be expected. In plants where there are chloride compounds in the indoor atmosphere, combustion air should be taken from outdoors.

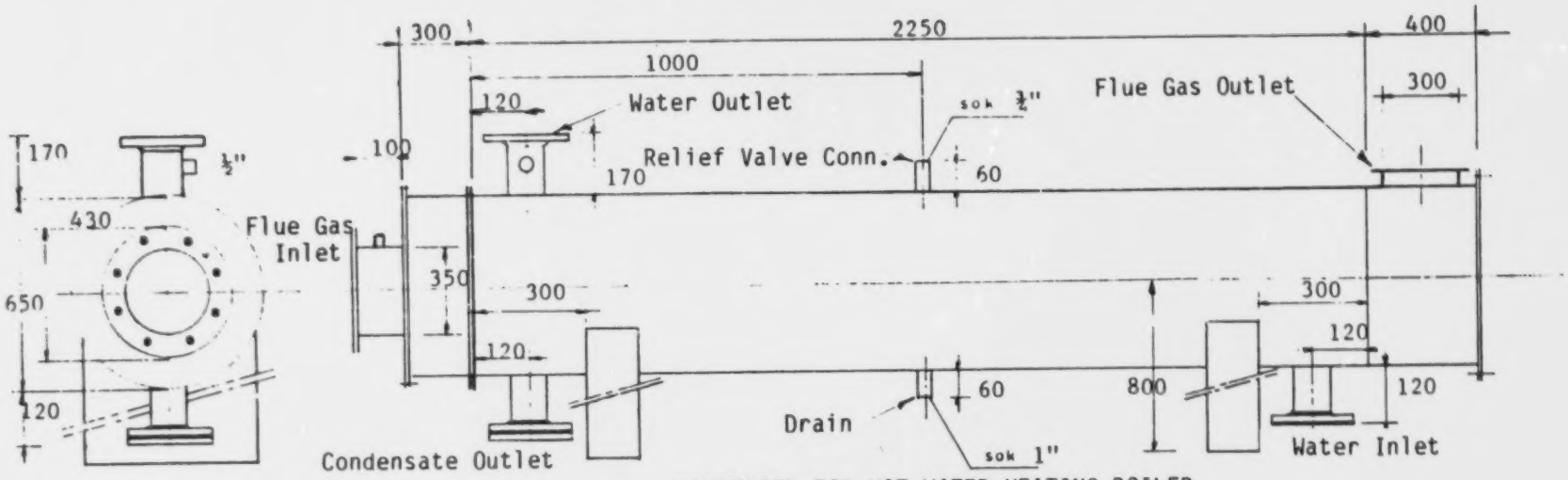
5.2 DESCRIPTION OF SYSTEMS

Flue gas condensation potentials for the two steam boilers and the Superhot hot water heating boiler were studied. One common system for the two steam boilers was considered because the boilers are small, they are pressure fired and need no complicated induced fan arrangement

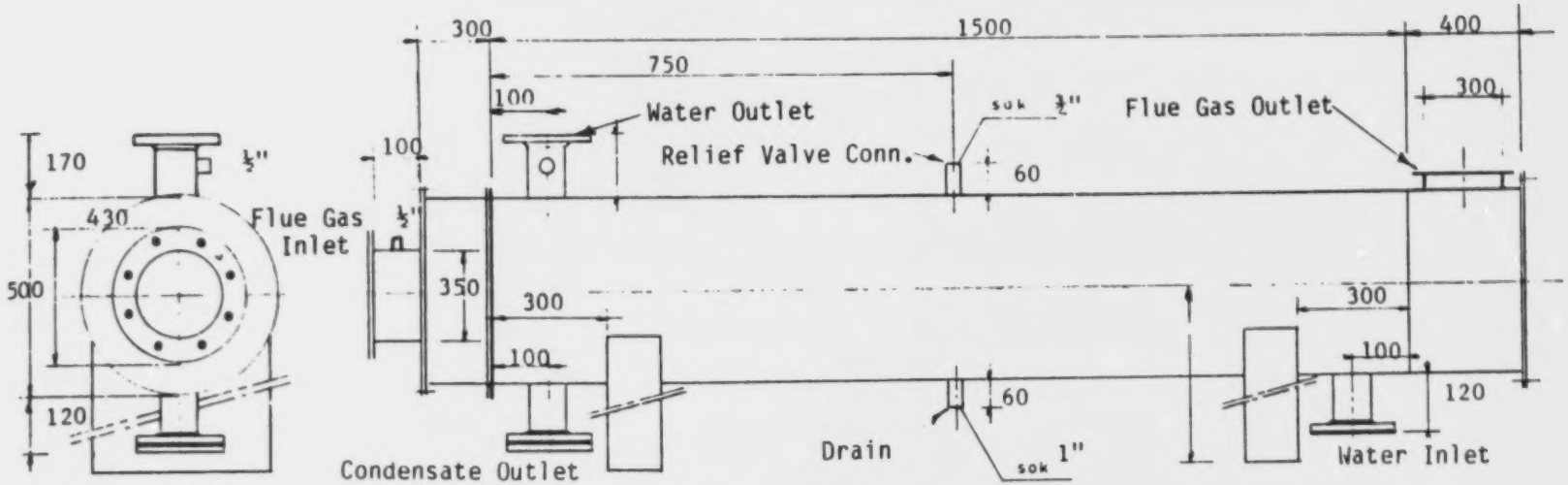
for varying flue gas flows, and the cost of a common condenser for the two boilers would only be about one third more than the cost of a condenser for one boiler. Although, as a rule, the Cleaver-Brooks steam boiler functions as the base-load boiler with the Volcano boiler taking up overload, there are times when the roles are reversed.

Since all boilers operate on an on/off cycle, boiler on-periods do not always coincide with hot water demand which, for purposes of condensation heat recovery, means that flue gases and water to be preheated in cooling the condenser are not always available at the same time. Therefore, for each condenser a common cold and hot water surge or retention tank is necessary from which water may be recirculated to the condenser in periods of no hot water demand. In addition, each condenser system will need maximum high temperature protection, such that when a preset maximum temperature is exceeded, as by no hot water demand for a prolonged period, fuel to the boiler will be shut off or the flue gases diverted directly to the atmosphere.

Gas-tube flue gas condensers of aluminum alloy construction as manufactured by Enalco b.v. of Holland (see Appendix F) were selected for purposes of this work for reasons of product specifications, a 5-year guarantee, and price. The gas-tubes of this particular condenser have longitudinal fins on the inside surface and thus offer an advantage of water-tube condensers of extended heat transfer surface on the gas-side where heat transfer is more difficult. Also, the aluminum alloy construction results in a physically smaller and less weighty condenser than one of the same type in steel construction -- an advantage in this instance because of limited space and absence of any heavy structural steel supports. Physical configuration of the condensers are shown in Figure 9.



CONDENSER FOR HOT WATER HEATING BOILER



CONDENSER FOR STEAM BOILERS

FIGURE 9 - PHYSICAL CONFIGURATION OF FLUE GAS CONDENSERS

5.2.1 Steam Boiler System

An engineering flow diagram for the condensation heat recovery system for the Cleaver-Brooks and Volcano steam boilers is shown in Figure 10. Briefly, a common plenum connects the two boiler stacks to the flue gas condenser located near the ceiling or outsite the boiler room. A dampered tee-section is placed just ahead of the condenser connection for diverting flue gases directly to atmosphere. Each boiler controls a separate condenser water supply pump such that flow of water through the condenser is more of less proportional to the flow of flue gases, the object being to obtain an approximate water temperature of 43°C leaving the condenser for use as boiler feedwater and as utility warm water. After leaving the condenser the warm water is held in a storage tank if periods of boiler on-cycle and warm water demand are not coincident. The storage tank also holds a reserve of cold water for recirculation to the condenser when one or both boilers are on on-cycle and there is no warm water demand -- hence fresh city water cannot be supplied directly to the pumps. Warm water for utility use after leaving the storage tank passes through a hot water heating and storage tank for any necessary increase in temperature. Because of the dual role of the storage tank of storing warm water in its upper part and cold water in its lower part, it should be designed to attain a stratified temperature profile in the tank. The goal is to fill the tank from the top and bottom with as little disturbance as possible between the hot and cold water layers.

Since steam and water demand patterns are variable and independent of each other no reliable mathematical approach is available for determining the storage capacity of the storage tank. Storage capacity was determined based on the following factors:

- About one half of the warm water output of the condenser is used for boiler feedwater more or less concurrently with boiler opera-

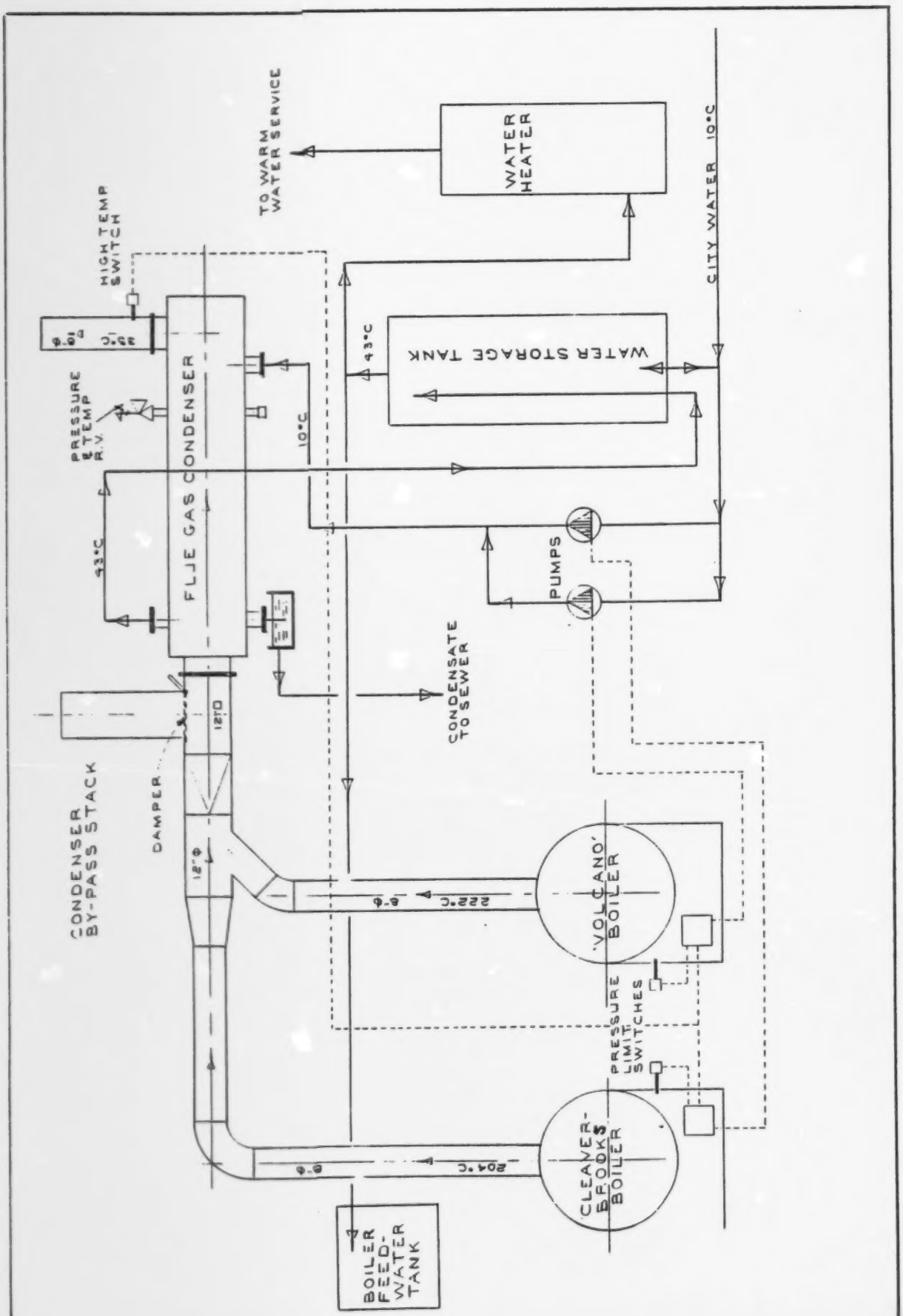


FIGURE 10 - FLOW DIAGRAM OF CONDENSATION HEAT RECOVERY SYSTEM FOR STEAM BOILERS

tion -- providing a consistent although intermittent draw from the storage tank. If steady state recirculating temperature conditions are allowed to be attained by no utility warm water being used for a sufficiently long period (depending on tank size), the worst that will occur will be an increase in condensing water temperature and a decrease in condenser heat recovery.

- The temperature of the warm water leaving the storage tank is not critical from the standpoint of use, since such water is presently used for boiler feed and for hot water heating tank supplies without preheat.

- The Cleaver-Brooks boiler is on about 60 percent of the time and the Volcano boiler about 25 percent of the time.

Using the above as guidelines, the storage tank capacity was sized for a net one-tank-volume exchange for a one-hour boilers operating period, assuming no mixing of hot and cold water layers for 70 percent of volume exchange. Using instantaneous water flow rates from Figure VIII, this would give a tank volume of,

$$\frac{(1{,}180 \times 0.60 + 1{,}063 \times 0.25) - (569 \times 0.60 + 476 \times 0.25)}{0.70}$$

= 736 l. (194 gal.)

This ratio of tank height to tank diameter should be about 4 to 1 to ensure at least a moderate degree of temperature stratification.

The system requires the following instrumentation and controls as indicated on the flow diagram in Figure 10:

- Boiler furnace over-pressure protection switch to shut down boiler and sound alarm in event of high boiler furnace pressure due to blockage of flue gas passages in condenser.

- Sequencing of circulating pump operation in accordance with boiler on/off cycles through boiler gas valves.

- Hot water high-temperature limit to discharge high-temperature water from storage tank at, say a temperature in the range of 88°C to 94°C.

- Manually operated condenser by-pass damper to discharge flue gases directly to atmosphere and continue boiler operating in event of any failure in the condensation heat recovery system.

- Flue gas and water inlet and outlet thermometers.

5.2.2 Hot Water Boiler System

An engineering flow diagram for the Superhot hot water heating boiler condensation heat recovery system is shown in Figure 11. The system is in many respects similar to that for the steam boilers. Because, the hot water boiler has atmospheric burners, elimination of the draft hoods and installation of an induced draft fan is needed to overcome flue gas pressure drop through the condenser. The boiler is run on high and low fire. Although low fire is on only momentarily the induced draft fan should preferably have a two-speed motor. System instrumentation and controls are the same as those for the steam boilers system with the addition of a pressure switch in the stack to prevent the boiler being fired until after the induced draft fan is running.

The purpose of the water storage tank is similar to that in the steam boilers system although temperature stratification is less critical because the temperature gain across the condenser is only about 13.5°C. Most often the firing of the boiler (i.e., on-cycle) and hot water draw-off from the hot water circuit occur at the same time. The function of the water storage tank is more to provide a reservoir for

water recirculation to the flue gas condenser during periods of no hot water demand than to act as a preheated water holding tank.

The water storage tank capacity sizing is based on a three-tank-volume exchange for a one hour boiler operating period, complete mixing of preheated and cold water in the tank and the boiler being on for 35 percent of the time. The tank size obtained using instantaneous flow data from Table VIII is,

$$\frac{8,066 \times 0.35}{3} = 941 \text{ l. } (249 \text{ gal.})$$

Space limitation within the building requires that the condenser be located above the roof of the building annex in which the hot water heating boiler is located.

5.3 SYSTEMS DESIGN

Measured and calculated design data for the two condensation heat recovery systems are summarized in Table VIII, the results of which are tabled below.

ITEM	STEAM BOILERS CB	STEAM BOILERS Volcano	HOT WATER BOILER
Excess air, %	7.4	15.0	57.6
Combustion system eff., %	82.0	80.9	78.5
Dew point temp., °C	58.4	57.0	51.2
Flue gas outlet temp. °C	35	35	35
Cond. water inlet temp., °C	10.0	10.0	10.0
Cond. water outlet temp., °C	43.0	43.0	23.5
Output of condenser, % of HHV	13.0	14.0	15.2
New boiler comb. system eff., % of HHV	95.0	94.9	93.7
Fuel saving, %	13.7	14.7	20.2*

* Includes 4.0% for reduction in standby losses.

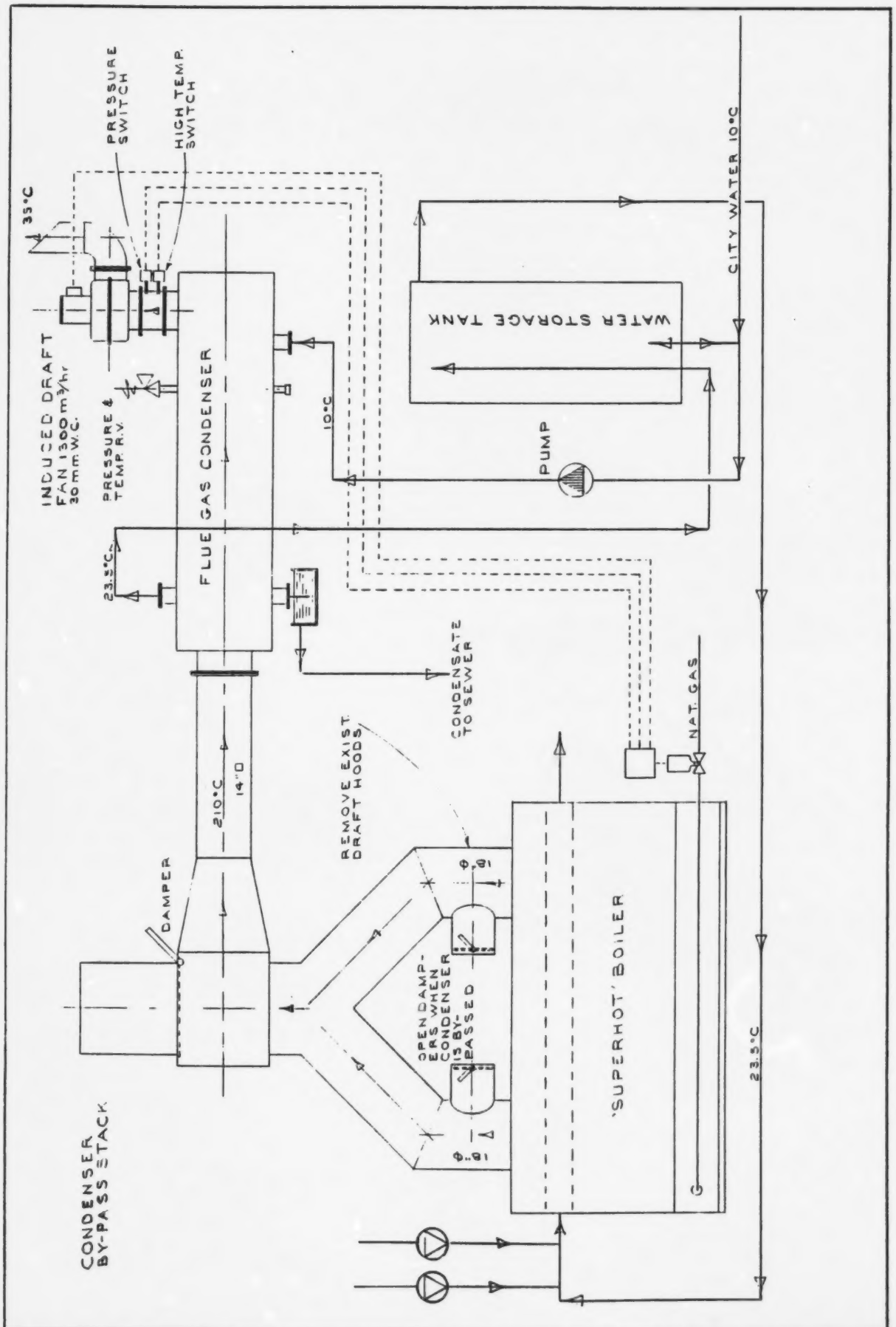


FIGURE 11 - FLOW DIAGRAM OF CONDENSATION HEAT RECOVERY SYSTEM FOR HOT WATER HEATING BOILER

The following values obtained using Figure 2 and Figure 5 are for purpose of comparison with the above respective calculated values only.

ITEM	STEAM BOILERS CB	STEAM BOILERS Volcano	HOT WATER BOILER
Heat recovered in cooling flue gas to 140°C (Fig. 2), % of HHV	84.5	84.2	82.3
Heat recovered in cooling flue gas from 140°C to 35°C (Fig. 5), % of HHV	11.0	11.1	11.6
New boiler comb. system eff., % of HHV	95.5	95.3	93.9

Note that the values for new boiler combustion system efficiency obtained from Figure 2 and Figure 5 are somewhat higher than the respective calculated values.

The hot water boiler has a high standby loss due to the boiler not being on-fire 65 percent of time. During the off period cold air is induced by natural draft across the boiler coils in which hot water is nearly always in circulation. The average temperature of flue gas and air passing upwards through the stack, above the draft hood, was estimated from measurements to be about 53°C (127°F). An estimate of standby losses due to the above effect follows.

At 170°F the draft is about 0.001" w.c./ft. of stack ht.
Stack ht. = 15 ft.
$\therefore$ total draft is 0.001 x 15 = 0.015" W.C.

Assume that the above total draft is dissipated as friction loss due to flow of gases in the stack

A convenient and reasonably accurate formula for calculating draft losses (DL) is,

TABLE VIII - DESIGN AND ECONOMIC EVAULATION SUMMARY FOR CONDENSATION HEAT RECOVERY SYSTEMS

	C.B. STEAM BOILER	VOLCANO STEAM BOILER	S.H. HOT WATER BOILER
O_2-content in flue gas, %	1.6	3.0	8.2
Flue gas temp. inlet, °C	204	222	210
Flue gas tem. outlet, °C	35	35	35
Vapour press. 35°C, mm Hg	42.2	42.2	42.2
Excess air, %	7.4	15.0	57.6
Vol. flue gas per m^3 nat. gas, Nm^3(1)	10.99	11.71	15.69
Wt. flue gas per m^3 nat. gas, kg	13.58	14.50	19.66
Vol. % H_2O in flue gas, %	18.10	17.04	12.86
Dewpoint temp., °C	58.4	57.0	51.2
Vapour press. at dewpoint, mm Hg	138.4	129.5	98.0
Combustion efficiency, % of HHV	82.0	80.9	78.5
Gas consumption, m^3/hr.	32.46	27.15	77.59
HHV of nat. gas, Kc/m^3 of nat. gas	9,235	9,235	9,235
Output boiler, kc/hr.	245,810	202,841	562,487
Wt. flue gas, kg/hr.	440.80	393.67	1,525.42
Condensation at 35°C, %	69.51	67.41	56.94
Latent heat, kc/m^3 of nat. gas	608.88	592.33	505.93
Sensible heat, kc/m^3 of nat. gas (2)	596.70	704.99	894.53
Heat recovered, kc/m^3 of nat. gas	1,205.58	1,297.32	1,400.41
Heat recovered in % of HHV	13.0	14.0	15.2
Inlet water temp., °C	10	10	10
Output of condenser, kc/hr.	38,970	35,102	108,620
Water thru condenser, l/hr.	1,180	1,063	8,066
Outlet water temp., °C	43	43	23.5
Condenser efficiency, %	82.9	84.4	93.2
Surface (water side) m^2	---------	By Manufacturer	----------
Surface (gas side) m^2	---------	By Manufacturer	----------
Boiler make-up water l/hr.	569	476	-
New combustion eff. % of HHV	95.0	94.9	93.7
Fuel saving, %	13.7	14.7	16.2
Addition fuel savings from decreased standby losses, % (3)	-	-	4.0
Total fuel savings, %	13.7	14.7	20.2
Input by fuel, MJ/day (4)	18,061	6,294	25,184
Fuel saving, MJ/day	2,474	925	5,087
Fuel unit price, $/1,000 MJ	3.75	3.75	3.75
Annual fuel saving, $/yr.	3,384	1,265	6,958
Total for steam boilers, $/yr.	4,649		
Condenser cost (landed) $ (5)	5,124		6,724
Condensation system installed, $ (1985) (1.6 x condenser cost)	8,198		10,758
Annual operating costs, $/yr.	140		230
Simple payback period, yr.	1.8		1.6

(1) m^3 of nat. gas is at 101.325 kPa and 15°C, Nm^3 at 101.325 kPa and 0°C.
(2) Assume specific heat of flue gas to be 0.26 kc/kg °C.
(3) See section 5.3.
(4) CB Boiler, Volcano boiler and Superhot boilers operate 60%, 25% and 35% of time.
(5) (Cost in Holland) x 1.68 to allow for transport, duty and taxes. Condensers are of counter current flow design.

$$(DL) = f\ W^2CH/A^3$$

where:

f = friction factor (= 0.0015 for steel stacks)
W = Lb/sec of stack gases
C = Inner circumference of stack in ft. (= 4.7 ft.)
H = Effective stack height in ft. (= 15 ft.)
A = Area of inside of stack in ft.^{2} (= 1.77 ft.^{2})

$$W = \sqrt{\frac{(DL) \times A^3}{f\ CH}}$$

$$= \sqrt{\frac{0.015 \times 5.54}{0.0015 \times 4.71 \times 15}}$$

$$= 0.88 \text{ lb./sec.}$$

Heat loss during standby assuming an average ambient temperature of 50°F is,

$$(127 - 50) \times 0.88 \times 3600 \times 0.24 = 63{,}400 \text{ Btu/hr.}$$

Since boiler operates 35 percent of time the percent heat loss (expressed as percent of HHV or boiler input) is,

$$\frac{63{,}400 \times 0.65}{3{,}000{,}000 \times 0.35} \times 100\% = 3.9\%$$

The above estimate was checked by measurement of air flow through the boiler air register and temperatures of air entering and leaving the furnace as follows:

Free area of air register	4.8 ft^2
Air velocity	70 ft./min.
Temperature of air entering furnace	60°F
Temperature of air leaving furnace (measured below draft hood)	240°F

Heat loss during standby period is

$$1.085 \times (240 - 60) \times (70 \times 4.8 \times 530/520) = 66,900 \text{ Btu/hr.}$$

which expressed as a percentage of input of HHV is,

$$\frac{66,900 \times 0.65}{3,000,000 \times 0.35} \times 100\% = 4.1\%$$

The standby heat loss accepted is an average of the above two values, 4.0%.

This heat loss would be practically eliminated with installation of a flue gas condensation system because of control of flue gas and air flow through the boiler by means of an induced draft fan which would operate only when the boiler is on on-fire. The total fuel saving in the case of the atmospheric-fired hot water boiler would then be the sum of fuel savings due to flue gas condensation and the above figure as shown in Table VIII - 16.2% + 4.0% = 20.2%.

Although the above figure of 4.0% might be viewed perhaps as being somewhat on the liberal side, this is compensated for by the possible benefits of decreased excess air (due to better draft control by induced draft fan) which would result in:

- a higher boiler combustion system efficiency,
- and improved flue gas condenser performance.

The ratio of latent heat to sensible heat in the heat recovered by the condenser would increase because of raising of dewpoint temperature due to decreased excess air) and even if the total heat recovered in the condenser remained the same the net result will still be an increase in new combustion system efficiency because of the increase in combustion system efficiency of the boiler alone.

Although the boilers are located in rather confined quarters there would be no difficulty in connecting their flues to the condensers because the flue piping size is small, being in the range of 203 mm (8") to 457 mm (18") in diameter. All associated water piping is also in small pipe sizes, hence routing of piping would present no location problems. Condenser location is flexible and may be indoors or outdoors to suit owner's preference. Since no layout drawings of the existing equipment are available and equipment layout in this case has an insignificant bearing on the capital cost of the flue gas condensation equipment, equipment layout drawings were found not necessary for purposes of this study.

5.4 ECONOMIC ASSESSMENT

Economic evaluation data summarized at the end of Table VIII are further summarized below.

ITEM	STEAM BOILERS	HOT WATER BOILERS
Fuel savings, MJ/day	3,399	5,087
Fuel unit price, $/1,000 MJ	3.75	3.75
Annual fuel saving, $/yr.	4,649	6,958
Condenser cost, $	5,124	6,724
Condensation system installed, $	8,198	10,758
Annual operating cost, $/yr.	140	230
Simple payback period, yr.	1.8	1.6

The above simple payback periods are based on the boilers operating roughly about an average of 33 percent of the available time. If the on-cycle periods are doubled the payback periods would be roughly one-half of the above values.

The economics of the two flue gas condensation systems, as indicated by simple payback periods, are attractive and their implementation is recommended.

5.5 FURTHER DISCUSSION AND CONCLUDING COMMENTS

The heat recovered by a flue gas condenser is a function of:

1. Flue gas entering temperature.
2. Cooling water entering temperature.
3. Moisture content of flue gas.
4. Flue gas dewpoint temperature.
5. Condenser heat exchange surface area.
6. Mass flow rates of flue gas and water.

The amount of flue gas moisture condensed increases directly with increasing values of 1, 3, 4, 5 and 6 and inversely with increasing values of 2.

Low percent excess air levels are all the more important in a condensing boiler because high excess air levels affect adversely the performance of both the boiler and the condenser. Note in the 4th group of data in Table VIII, that with increasing excess air while the percentage of total heat recovered also increases, this is due to the increased amount of sensible heat recovered as the quantity of latent heat recovered decreases. However, to accomplish the latter the size of the condenser must be increased; otherwise, the total heat recovered would not increase.

The development of flue gas condensation technology and market availability of equipment in the late 1970s and early 1980s has proceeded at a much faster pace in Europe, in countries such as Holland, Belgium and France, than in North America. Surface flue gas condensers for the small and average size industrial boilers generally are not readily available in North America. Hence, for the applications studied, the supply of flue gas condensers is predicated to be from Holland. Direct contact flue gas condensers based on European designs are available in North America, but there have been few applications and these have been

confined mainly to large boilers. They tend to be uneconomic for boilers in the lower size range.

Generally, European flue gas condensers are designed only for flue gases from natural gas. The Teflon lined water-tube surface condensers available in North America are claimed to be suitable for flue gases from sulphur-bearing liquid and gaseous fuels, but no such application was identified in this study.

Both direct and surface flue gas condensers are potentially capable of reducing gaseous and particulate pollutants. Accumulation of particulates on and corrosion of gas-side heat exchange surfaces by gaseous pollutants would decrease heat exchange in surface condensers and hence, adversely affect their performance. No problems with any of the above have been reported with condensers designed for natural gas. However, all flue gas condensers have accesses for cleaning heat exchange surfaces as, over time, there is potential for some corrosion and accumulation of particulate matter from pollutants in combustion air if not the fuel itself. The characteristics or quality of the cooling water control solid deposits and corrosion of water-side heat exchange surfaces. Corrosion of the shell in gas-tube condensers and of the housing in water-tube condensers would not affect heat exchange effectiveness except, possibly, condenser life. As mentioned earlier, the interior of the housing of the flue gas water-tube condenser at Site No. 1 was found to be corroding.

Potential for application of flue gas condensation to industrial boilers usually exists where there is a usable low temperature heat sink. Typically, this sink is a low temperature heating medium in a closed heating circuit or water that is available for preheat in the flue gas condenser prior to consumptive use. The following are some examples:

1. Preheat of water in a hot water heating boiler in establishments such as slaughter-houses, dairies, laundries, hospitals and swimming pools.

2. Preheat of boiler make-up feedwater.

3. Soil heating water circuits in greenhouses.

4. Floor heating water circuits.

5. Pool heating.

6. Snow and ice melting.

In cold climates, a separate condenser space heating circuit may be employed to maintain room temperatures above freezing with addition of an anti-freeze to the water -- i.e., heating applications not requiring comfort heating, such as warehouses.

Estimated fuel savings for flue gas condensation systems for the study plant are in the range of 13.7 to 20.2 percent of HHV. They are somewhat higher than the estimated savings for Site No. 1 and Site No. 2, which are in the range of 10.7 to 12.3 percent of HHV. The higher fuel savings for the study plant are attributed to higher flue gas temperatures leaving the boilers and lower cooling water temperature entering the condenser, resulting altogether in a higher condenser efficiency and fuel savings due to decreased standby losses for the atmospheric fired boilers.

Estimated simple payback periods for the steam boilers and hot water heating boiler flue condensation systems are 1.8 years and 1.6 years respectively. Estimated simple payback periods for Site No. 1 and Site No. 2 are 3.1 years and 1.6 years respectively. Estimates of simple payback periods for Site No. 1 and Site No. 2 are less accurate than

those for the study plant because, for the former, annual fuel usages had to be estimated rather than taken from actual records. They are also longer because the boiler at Site No. 1 and Site No. 2 are used only during the heating season. However, it can be said that all estimated simple payback periods indicate attractive investments. A further benefit from flue gas condensation at Site No. 1 and Site No. 2 is that the cooled flue gases can be utilized as carbon dioxide sources in greenhouses with significant results.

No impediments are foreseen in the implementation of the study flue gas condensation systems. At the beginning of the study the stand taken by British Columbia gas inspection authorities was to neither approve or disapprove the flue gas condensation installations at Site No. 1 and Site No. 2. This was largely due to the inspectors having little or no previous experience with such equipment. However, recently the situation has changed, apparently because of safe operation of the Site No. 1 and Site No. 2 systems, and inspection authorities have agreed to approve such systems provided, of course, that certain safety requirements are met.

APPENDIX A - Performance Test Report of Flue Gas Condenser at Site No. 1 by B.C. Hydro

PROJECT 8315

TOTAL ECO RECUPERATOR PERFORMANCE TESTS

SYNOPSIS:

The Total Eco recuperator is a device made in Holland for recovering heat from natural gas-fired boiler flue gases.

Tests on a unit installed on a 100 HP hot water boiler in Langley, B. C. show gas savings of some 13%, (based on fuel input).

The recuperator installation resulted in boiler de-rating by a net 23% (i.e. from 100 HP to 77 HP), a situation which could cause difficulties in some installations.

Provided the de-rating problem can be resolved and no deterioration due to corrosion develops, there could be many applications in B. C. for this unit.

PROJECT:

Initiated by:	C. L. Dyble
Date Completed:	April 1984
Completed by:	C. F. Mason
Supervised by:	D. Henriques
Approved by:	R. W. Racine, Manager Energy Use Engineering
Initial Distribution:	D. Henriques C. L. Dyble W. Malkin I. Killacky T. Newton

JR21.11

ENERGY USE ENGINEERING DEPARTMENT

PROJECT SUMMARY

PROJECT No. 8315 PRIORITY 2

TITLE: TOTAL ECO Recuperator Performance Tests

INITIATED/REQUESTED BY: C. L. Dyble

ASSIGNED TO: C. F. Mason ASSIGNED BY: M. W. Bodnar

DATE ASSIGNED: March 1983 DATE REQUIRED: April 1984

ESTIMATED COMPLETION: April 1984 COMPLETED: April 1984

OBJECTIVES AND NOTES:

The objective is to determine the savings in natural gas which can be achieved through the retrofitting of the heat exchanger (condensation type) to a 100 HP boiler.

Measurements required include:

1. Natural gas flow to boiler.
2. Flue gas temperature at boiler outlet.
3. Flue gas temperature at recuperator outlet.
4. Boiler efficiency measurements at various loads.

This heat exchanger was imported from Holland in mid-1983, and its application is expected to increase boiler efficiency by 10% or more.

COPIES TO: DEPARTMENT MANAGER (THEN RECORD FILE), BLUE FILE, SUPERVISOR, (G.D.A. Henriques)
EUE Supervisors C. L. Dyble
I. R. Killacky, Lochburn
H. W. Malkin, Fraser Valley Gas

PLEASE ADVISE AS SOON AS POSSIBLE IF CHANGES ARE REQUIRED ABOVE

TABLE OF CONTENTS

		Page
1.	SUMMARY	1
2.	CONCLUSIONS	1
3.	INTRODUCTION	1
4.	PLANT DESCRIPTION	2
5.	TEST REQUIREMENTS AND PROCEDURES	2
6.	TEST RESULTS	5
7.	DISCUSSION OF RESULTS	5
8.	ACKNOWLEDGEMENTS	7
TABLE OF RESULTS		8

APPENDIX I - Total Eco Literature
APPENDIX II - Account Information

1. SUMMARY

The Total Eco Recuperator is a device designed to recover sensible and latent heat from boiler flue gases. Combustion efficiency is raised from the current 80%± value to over 90%.

Tests carried out on a Total Eco Recuperator fitted to a 100 HP boiler showed the following savings (as a percentage of fuel input):

Low Fire	(35% rating):	14.1%
Medium Fire	(69% rating):	11.9%

For the installation tested, the future annual fuel savings were estimated at 585 GJ, with a monetary value of some $2,500.

2. CONCLUSIONS

2.1 The increase in Fuel-to-Water Efficiency with the recuperator is about 10%, as anticipated, and the calculated fuel savings (12-14%) are of the order expected.

2.2 The imposition of the recuperator on the flue system resulted in a de-rating of the boiler to a net 77% of the maximum design output. It was not possible to fire the boiler at 100% rating. Boiler de-rating could cause difficulties in certain installations, and should be kept to a minimum. (Ref. Section 7.2 for suggested methods of increasing firing capability.)

2.3 Provided the de-rating problem can be resolved, and there are, in addition, no corrosion difficulties, the Total Eco Recuperator could be an effective energy recovery device, when properly applied.

3. INTRODUCTION

For maximum efficiency in any heating process, losses of energy from the system should be kept to a minimum. In the case of a boiler, the heat carried away in the flue gases represents a major loss which can be reduced by a heat recovery device inserted in the flue. Fuel savings of between 10 and 16% are possible using this method of recuperation.

The Total Eco Recuperator is a heat exchanger normally fitted into a natural gas-fired boiler flue and is designed to recover both sensible and latent heat from the flue gases. The latent heat represents over 80% of the heat recovered, and the heat recovery device is sometimes referred to as a condensation heat exchanger.

This report gives the results of tests carried out on a Total Eco Recuperator fitted to a boiler used in the heating of a commercial greenhouse in Langley, B. C. The greenhouse facility is owned and operated by Mr. George Revenek.

The key to the successful application of a condensation heat exchanger is in finding a use for the low grade heat recovered. The fuel savings indicated in this report are based on the assumption that all the recovered heat is usefully employed.

4. PLANT DESCRIPTION

The greenhouses are heated by hot water provided principally by a 100 HP Saskatoon gas-fired packaged boiler. An additional boiler is available for emergency use. The Total Eco system was imported from Holland and installed in the summer of 1983. The recovered heat is used to warm water used for soil heating and also to preheat return water from the main greenhouse heating system.

The Total Eco Recuperator consists of the two sets of aluminum finned copper tubes fitted into a (reportedly) corrosion-resistant steel housing. One set of tubes serves the soil heating system and the other the main greenhouse operation. Flue gases pass over the tubes where heat is exchanged between the flue gases and water flowing through the tubes. The temperature of the flue gases is reduced to less than the dew point of the flue gases, and condensation takes place on the heat exchanger. (The dew point of the flue gases is related to the amount of excess combustion air, and ranges, typically, from 58°C (136°F) for 10% excess air to 47°C (116°F) for 100% excess air.) Condensate is discharged from the unit through a drain at the bottom.

Figures 1 and 2 show the general arrangement. (Note the by-pass flue for use when the recuperator has to be taken out of service.)

5. TEST REQUIREMENTS AND PROCEDURES

A complete test and evaluation of the recuperator would require a heat balance for which measurements on the water-side of the unit would be necessary. As the meters for this work were not readily available, the tests were conducted on the gas-side only. The results are deemed to be sufficiently accurate to give an acceptable measure of overall boiler performance.

Flue gas temperatures and analyses (for CO_2 and CO, using Drager tubes) were taken at the boiler flue and recuperator exits for low and medium firing rates. (The boiler will not operate at High Fire (100% rating) when the recuperator is part of the exhaust gas system. Refer to Section 7.2 for further discussion.)

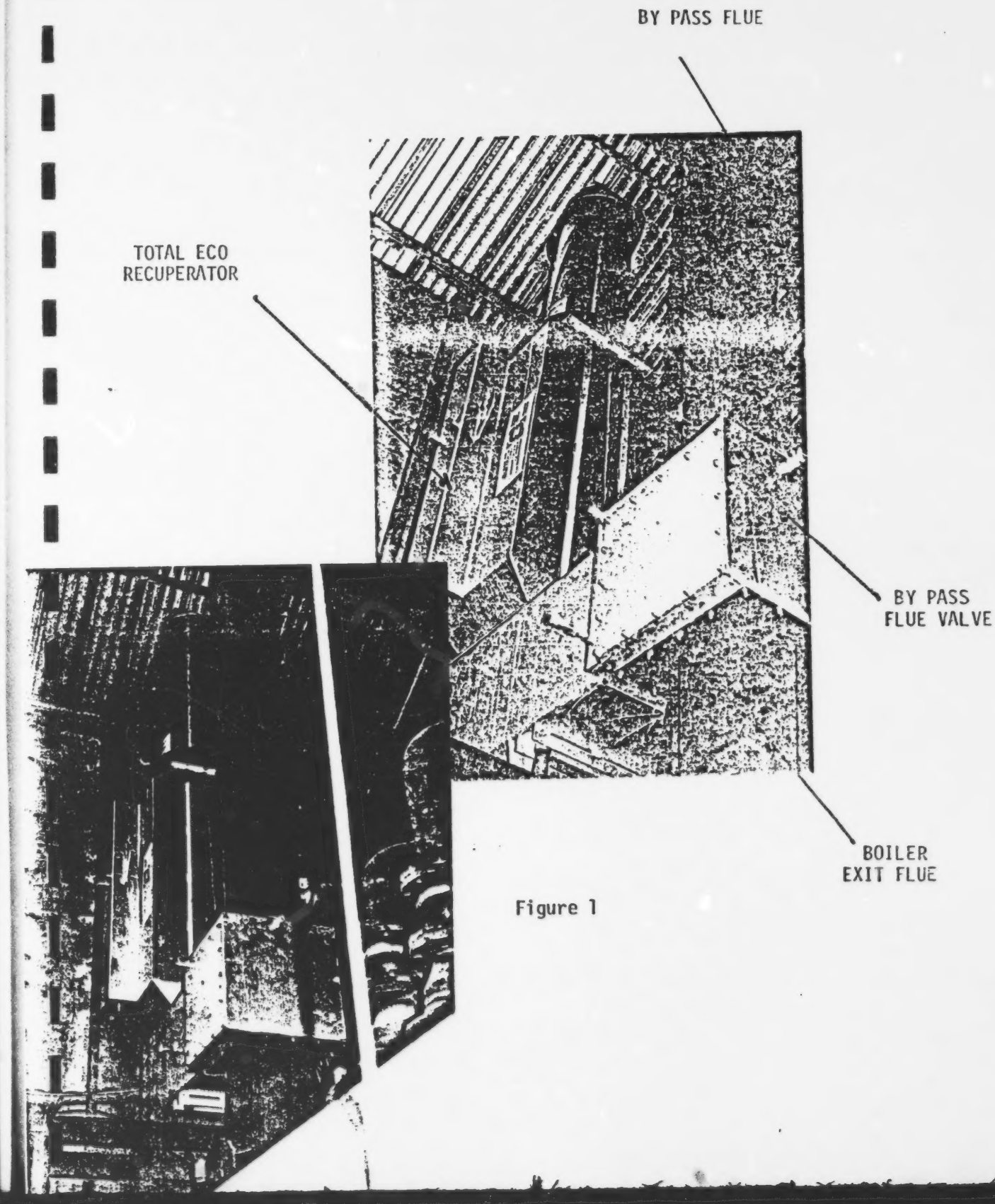

BY PASS FLUE
TOTAL ECO
RECUPERATOR
BY PASS
FLUE VALVE
BOILER
EXIT FLUE

Figure 1

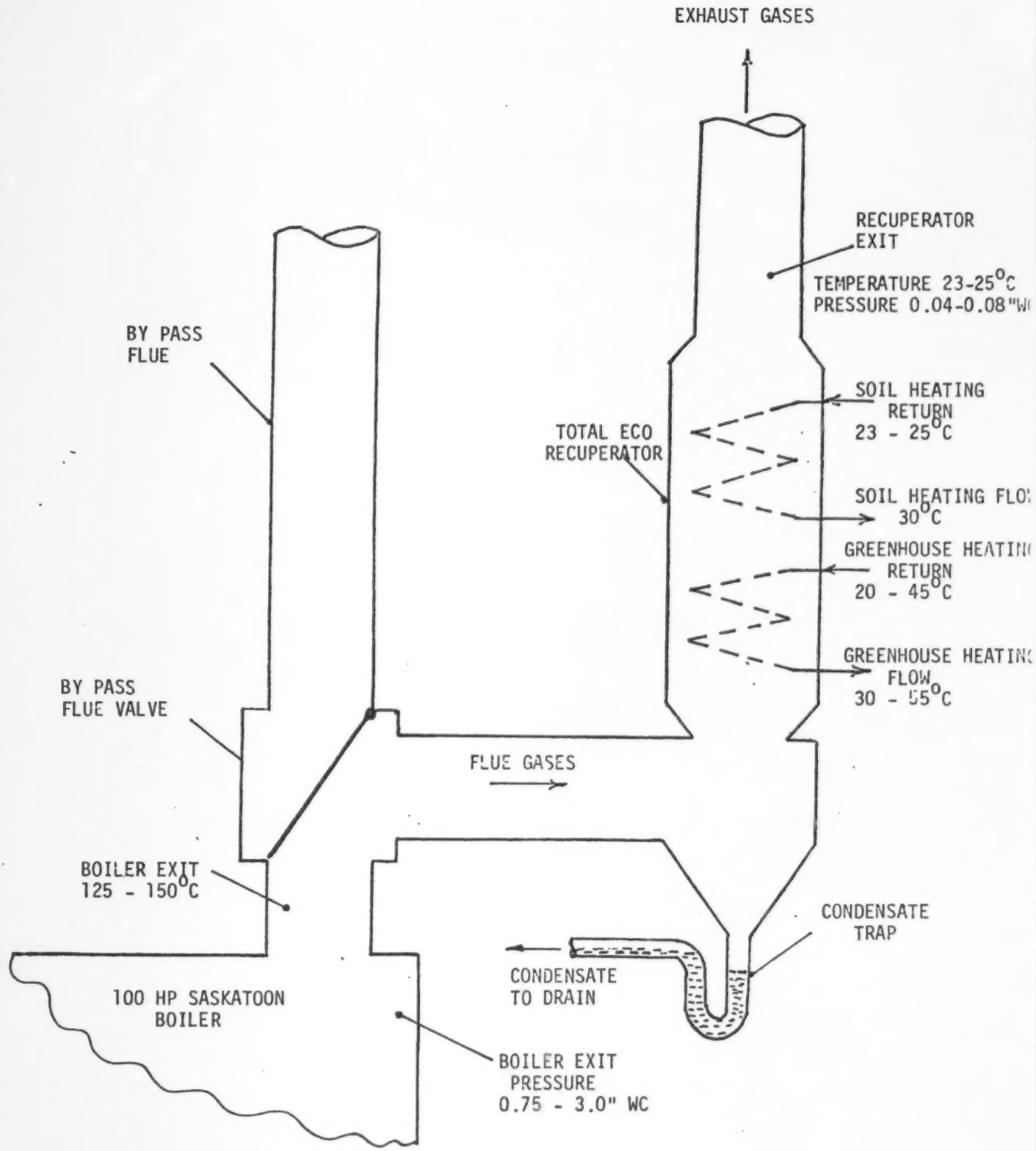

EXHAUST GASES
RECUPERATOR EXIT
TEMPERATURE 23-25°C
PRESSURE 0.04-0.08"W
BY PASS FLUE
SOIL HEATING RETURN
23 - 25°C
TOTAL ECO RECUPERATOR
SOIL HEATING FLO
30°C
GREENHOUSE HEATIN
RETURN
20 - 45°C
GREENHOUSE HEATIN
FLOW
30 - 55°C
BY PASS FLUE VALVE
FLUE GASES
BOILER EXIT
125 - 150°C
CONDENSATE TRAP
CONDENSATE TO DRAIN
100 HP SASKATOON BOILER
BOILER EXIT PRESSURE
0.75 - 3.0" WC

Figure 2

The flue gas pressure was taken at the boiler flue exit. As the recuperator gas outlet flue was only some 10 ft. in length and discharged to atmosphere, a calculated allowance was made for the pressure at the recuperator exit.

6. TEST RESULTS

The results are tabulated on page 8.

There was a water temperature rise of 10°C (18°F) at Low Fire across the coil used for the greenhouse heating system. As water flow rate measurements were not taken, this figure is of little value, except to indicate that heat transfer was taking place. (Typical water temperatures are shown in Figure 2.)

The excess air levels were calculated from the CO_2 values, and the flue losses were derived from the excess air and flue gas temperatures. The recuperator stack loss included for the latent heat of condensation.

The boiler shell losses were taken as 2% of the gross thermal input at High Fire, this value being based on experience with similar plant elsewhere. As the quantity of heat lost from the shell is almost independent of firing rate, the shell losses for other firing rates, as a percentage of the fuel input, were pro-rated.

The total loss is the sum of the flue loss and boiler shell losses. The Fuel-to-Water Efficiency was then obtained from the difference between the thermal input and the total losses at a particular firing rate. Hence:

Fuel-to-Water Efficiency = 100% - (Flue Loss + Shell Loss)%

Fuel saving, expressed as a percentage of fuel input, is based on the formula:

$$\% \text{ Fuel Saving} = \frac{\text{Improvement in Efficiency} \times 100}{\text{Original Efficiency}}$$

7. DISCUSSION OF RESULTS

7.1 Efficiency and Energy Savings

Combustion efficiency at the boiler exit (100 - Boiler Flue Loss)% was above 80% - an acceptable level. The absence of CO indicated that the recuperator did not impede the combustion process.

The combustion efficiency at the recuperator outlet (100 - Recuperator Stack Loss)% is above 90% - an acceptable figure.

The recuperator resulted in a reduction in the flue loss of between 9.5 and 10.7%, for estimated savings of between 11.9 and 14.1% of the fuel input (13% average), depending on the firing rate.

Such a reduction in flue loss and estimated savings are of the order expected.

An accurate estimate of savings using gas billing data for corresponding periods in 1982/83 and 1983/84 was not possible due to the influence of certain variables, including:

1. An automatic curtain (heat retention) system which was installed in mid-1983. Fuel savings due to the curtain are unknown.

2. Weather. The extent to which the fuel use is weather sensitive is not known with sufficient accuracy.

Account information for the periods mentioned are contained in Appendix II.

Any assessment of savings based on comparisons of energy use with other greenhouses in the area could be meaningless owing to widely differing management and operating conditions.

However, on the assumption of a future annual gas consumption of 4500 GJ, the avoided consumption due to the recuperator would be (4500 GJ x 0.13) = 585 GJ. The monetary value of such a saving would be of the order of $2,500.

The installed cost of the recuperator was reportedly $7,000, giving a simple payback on the investment of some 2.8 years.

7.2 Pressure Drop

The immediate effect of fitting the recuperator was to reduce the boiler's maximum fuel input to about 69% of the rated value. (The rated value had been attainable before the recuperator was installed.) However, the reduction in input capability was partially offset by an increase of some 12% of output due to the efficiency gain.

Thus, the net result of the recuperator installation was to reduce the rating of the boiler from 100% to about 77% (69% + 69% x 0.12). This reduction is to be expected in view of the relatively high pressure drop (about 3.0"WC) across the flue system under Medium Fire conditions.

The reduction in rating could be a serious problem under certain circumstances. (It is understood that Mr. Ravenek was able to operate his boiler satisfactorily during the extremely cold December of 1983 because the boiler is oversized.)

Suggested methods of minimizing the amount of boiler de-rating (i.e. increasing the firing rate) are:

1. Redesign the flue gas piping and system to give minimum pressure drop. (This is only a partial solution.)

Either 2. Install an induced draft fan at the boiler outlet.

Or 3. Modify the existing gas burner system to operate with a sufficiently high combustion air pressure.

Any of the above changes would require Provincial Gas Inspector approval.

7.3 Corrosion

It is understood that there is no evidence of corrosion to-date. If practicable, an inspection of the heat exchanger surface should be made after about a year's operation.

ACKNOWLEDGEMENTS

B. C. Hydro wishes to thank Mr. George Ravenek for his cooperation and help throughout this project.

The assistance of the Industrial Services Section of the Fraser Valley Gas Division and C. L. Dyble, Agricultural Specialist for B. C. Hydro's Lower Mainland Division, is gratefully acknowledged.

TABLE OF RESULTS
TEST ON TOTAL ECO HEAT EXCHANGER AT
G. RAVENEK GREENHOUSE, 2425 - 48th AVENUE, LANGLEY, B. C.

DATE OF TEST: 28 February 1984
BOILER DATA: Saskatoon FWL G100; Hot Water; Serial 2310; Rated input: 4,184 ft^3/h natural gas at 1,000 Btu/ft^3
HHV GAS: 38.9 MJ/m^3 = 1,045 Btu/ft^3

	UNITS	LOW FIRE	MEDIUM FIRE	HIGH FIRE
Boiler Exit				
CO_2	%	5	7	
Excess Air	%	122.2	61.8	
CO	%	0	0	
Temperature	°C (°F)	125(257)	150(302)	
Pressure	"WC	0.75-0.80	2.8-3.0	
Recuperator Exit				
Temperature	°C (°F)	36(96.8)	43.5(110.3)	
Pressure	"WC	0.04*	0.08*	
Gas Rate	ft^3/h	1385	2770	Rated Input
Heat Input	10^6 Btu/h	1.447	2.894	not attainable
Rating	%	34.6	69.2	100
Boiler Shell Loss	%	5.8	2.9	
Boiler Flue Loss	%	18.1	17.5	
Recuperator Stack Loss	%	7.4	8.0	
Fuel-to-Water Efficiency before Recuperator	%	76.1	79.6	
Fuel-to-Water Efficiency with Recuperator	%	86.8	89.1	
Estimated Saving (fuel input basis)**	%	14.1	11.9	

* Calculated

** Estimated Savings = $\frac{\text{Improvement in Efficiency}}{\text{Original Efficiency}} \times 100\%$

84/03/28: CFM
Energy Use Engineering

Energy Conservation Division
B. C. Hydro

JR21.11

```
**********************
*                    *
*     CALCULATION    *
*         OF         *
*         A          *
*     VARIOCOMBI     *
*                    *
**********************

PROJECT
RAVENEK   (half load)

DATASECTIONNUMBER        1
NUMBER OFELEMENTS        8
ELEM.PARALEL             1
WATERINLET TEMP C       38
WATERQUANTITm3/h        12
GASQUANTITY m3/h        75
FLUEGASQUANTYTm3/h      781.76
FLUEGASINLET TEMP C     140


RESULTS SECTION          1
CAPACITY  SECTION kcal/h
 63809
TOTAL CAPACITY     kcal/h
 63809
WATEROUTLET TEMP C
 43.3174166667
FLUEGASOUTLET TEMP      43.136
CONDENS SECTIONIN l/h 65.096
TOTAL CONDENSQUANTl/h 65.096



DATASECTIONNUMBER        2
NUMBER OFELEMENTS        2
ELEM.PARALEL             1
WATERINLET TEMP C       30
WATERQUANTITm3/h        10
GASQUANTITY m3/h        75
FLUEGASQUANTYTm3/h      781.76
FLUEGASINLET TEMP C     43.136


RESULTS SECTION          2
CAPACITY  SECTION kcal/h
 24151
TOTAL CAPACITY     kcal/h
 87960
WATEROUTLET TEMP C      32.4151
FLUEGASOUTLET TEMP      42.513
CONDENS SECTIONIN l/h 41.914
TOTAL CONDENSQUANTl/h 107.01

SAVING IN % FROM
     7560 KCAL/M3GAS
 15.5132275132

CAPACITY INCREASEMENT OF THE TOT
ALINSTALLATION IN%=
 16.824284158

ORDER-CODE      Z1/10 &1 - 2.1
```

```
**********************
*                    *
*     CALCULATION    *
*         OF         *
*         A          *
*     VARIOCOMBI     *
*                    *
**********************

PROJECT
RAVENEK   (full load).

DATASECTIONNUMBER        1
NUMBER OFELEMENTS        8
ELEM.PARALEL             1
WATERINLET TEMP C       38
WATERQUANTITm3/h        12
GASQUANTITY m3/h        150
FLUEGASQUANTYTm3/h      1563.5
FLUEGASINLET TEMP C     175


RESULTS SECTION          1
CAPACITY  SECTION kcal/h
 114960
TOTAL CAPACITY     kcal/h
 114960
WATEROUTLET TEMP C      47.58
FLUEGASOUTLET TEMP      53.338
CONDENS SECTIONIN l/h 86.065
TOTAL CONDENSQUANTl/h 86.065



DATASECTIONNUMBER        2
NUMBER OFELEMENTS        2
ELEM.PARALEL             1
WATERINLET TEMP C       30
WATERQUANTITm3/h        10
GASQUANTITY m3/h        150
FLUEGASQUANTYTm3/h      1563.5
FLUEGASINLET TEMP C     53.338


RESULTS SECTION          2
CAPACITY  SECTION kcal/h
 34215
TOTAL CAPACITY     kcal/h
 149175
WATEROUTLET TEMP C      33.4215
FLUEGASOUTLET TEMP      50.471
CONDENS SECTIONIN l/h 55
TOTAL CONDENSQUANTl/h 141.065

SAVING IN % FROM
     7560 KCAL/M3GAS
 13.1547619048

CAPACITY INCREASEMENT OF THE TOT
ALINSTALLATION IN%=
 14.5279234753

ORDER-CODE      Z1/10 &1 - 2.1
```

APPENDIX B - Performance Test Report of Flue Gas Condenser at Site No. 2 by B.C. Hydro

PROJECT 8503

DALSEM HEAT EXCHANGER (RECUPERATOR) PERFORMANCE TESTS

SYNOPSIS:

The Dalsem Recuperator is a device made in Holland for recovering heat from natural gas-fired boiler flue gases.

Tests on a unit installed on a 350 HP hot water boiler in Pitt Meadows, B. C. show gas savings of some 13%, (based on fuel input).

The recuperator installation resulted in boiler de-rating by a net 9% (i.e. from 350 HP to 320 HP), a situation which could cause difficulties in some installations.

Provided the de-rating is either acceptable or compensated for and no appreciable deterioration due to corrosion develops, there could be many applications in B. C. for this unit.
(Note: Any changes to a gas installation, such as de-rating, and which affect performance must have prior Gas Inspector approval.)

PROJECT:

Initiated by:	C. L. Dyble
Date Completed:	February 1985
Completed by:	C. F. Mason
Supervised by:	G.D.A. Henriques
Approved by:	R. W. Racine, Manager Energy Use Engineering
Initial Distribution:	D. Henriques C. L. Dyble W. Malkin I. Killacky E. H. Williams

JR21.11

ENERGY USE ENGINEERING DEPARTMENT

PROJECT SUMMARY

PROJECT NO. 8503 PRIORITY 2

TITLE: Dalsem Heat Exchanger (Recuperator) Performance Tests

INITIATED/REQUESTED BY: C. L. Dyble

ASSIGNED TO: C. F. Mason ASSIGNED BY: G.D.A. Henriques

DATE ASSIGNED: October 1984 DATE REQUIRED: February 1985

ESTIMATED COMPLETION: February 1985 COMPLETED: February 1985

OBJECTIVES AND NOTES:

The objective is to determine the savings in natural gas which can be achieved through the fitting of a condensation type heat exchanger (recuperator) to a 350 HP Cleaver-Brooks hot water boiler.

Measurements required include:

1. Natural gas flow to boiler.
2. Flue gas temperature at boiler outlet.
3. Flue gas temperature at heat exchanger outlet.
4. Boiler efficiency measurements at various loads.

This heat exchanger was imported from Holland in mid-1984, and its application is expected to increase boiler efficiency by 10% or more.

COPIES TO: DEPARTMENT MANAGER (THEN RECORD FILE), BLUE FILE, SUPERVISOR,

EUE Supervisors I. R. Killacky, Lochburn

C. L. Dyble H. W. Malkin, Fraser Valley Gas

PLEASE ADVISE AS SOON AS POSSIBLE IF CHANGES ARE REQUIRED ABOVE

TABLE OF CONTENTS

		Page
1.	SUMMARY	1
2.	CONCLUSIONS	1
3.	INTRODUCTION	1
4.	PLANT DESCRIPTION	2
5.	TEST REQUIREMENTS AND PROCEDURES	2
6.	TEST RESULTS	5
7.	DISCUSSION OF RESULTS	5
8.	ACKNOWLEDGEMENTS	7
TABLE OF RESULTS		8

1. SUMMARY

The Dalsem Heat Exchanger (Recuperator) is a device designed to recover sensible and latent heat from boiler flue gases. Combustion efficiency is raised from the current 80%± value to over 90%.

Tests carried out on a Dalsem Recuperator fitted to a 350 HP boiler showed the following savings (as a percentage of fuel input):

Low Fire	(31% rating):	12.9%
High Fire	(81% rating):	12.5%

For the installation tested, the future annual fuel savings were estimated at 2150 GJ, with a monetary value of some $9,500.

2. CONCLUSIONS

2.1 The increase in Fuel-to-Water Efficiency with the recuperator is about 10%, as anticipated, and the calculated fuel savings (12.5-12.9%) are of the order expected.

2.2 The imposition of the recuperator on the flue system resulted in a de-rating of the boiler to a net 91% of the maximum design output. It was not possible to fire the boiler at 100% rating. Boiler de-rating could cause difficulties in certain installations, and should be kept to a minimum. (Ref. Section 7.2 for suggested methods of increasing firing capability.)

2.3 Provided the de-rating problem can be resolved, and there are, in addition, no corrosion difficulties, the Dalsem Recuperator could be an effective energy recovery device, when properly applied.

3. INTRODUCTION

For maximum efficiency in any heating process, losses of energy from the system should be kept to a minimum. In the case of a boiler, the heat carried away in the flue gases represents a major loss which can be reduced by a heat recovery device inserted in the flue. Fuel savings of between 10 and 16% are possible using this method of recuperation.

The Dalsem Heat Exchanger Recuperator is normally fitted into a natural gas-fired boiler flue and is designed to recover both sensible and latent heat from the flue gases. The latent heat represents over 80% of the heat recovered, and the heat recovery device is sometimes referred to as a condensation heat exchanger.

This report gives the results of tests carried out on a Dalsem Heat Exchanger fitted to a boiler used in the heating of a commercial greenhouse in Pitt Meadows, B. C. The greenhouse facility is owned and operated by Mr. A. van Marrewyk.

The key to the successful application of a condensation heat exchanger is in finding a use for the low grade heat recovered. The fuel savings indicated in this report are based on the assumption that all the recovered heat is usefully employed.

4. PLANT DESCRIPTION

The greenhouse is heated by hot water provided principally by a 350 HP Cleaver-Brooks gas-fired packaged boiler. The Dalsem system was imported from Holland and installed in the summer of 1984. The recovered heat is used in a warm water circuit for soil heating.

The Dalsem Heat Exchanger consists of a set of steel tubes fitted into a steel housing. Flue gases pass through the tubes, exchanging heat with the surrounding water flowing in the opposite direction.

The temperature of the flue gases is reduced to less than the dew point of the flue gases, and condensation takes place on the heat exchanger. (The dew point of the flue gases is related to the amount of excess combustion air, and ranges, typically, from 58°C (136°F) for 10% excess air to 47°C (116°F) for 100% excess air.) Condensate is discharged from the unit through a drain at the bottom. The heated water is distributed into the greenhouse through a piping system.

All surfaces of the heat exchanger which are in contact with the flue gas or condensate are (reportedly) protected with an epoxy tar coating.

Figures 1 and 2 show the general arrangement. (Note the exhaust gas by-pass for use when the recuperator has to be taken out of service.)

5. TEST REQUIREMENTS AND PROCEDURES

A complete test and evaluation of the recuperator would require a heat balance for which measurements on the water-side of the unit would be necessary. As the meters for this work were not readily available, the tests were conducted on the gas-side only. The results are deemed to be sufficiently accurate to give an acceptable measure of overall boiler performance.

Flue gas temperatures and analyses (for CO_2 and CO, using Drager tubes) were taken at the boiler flue and recuperator exits for low and high firing rates.

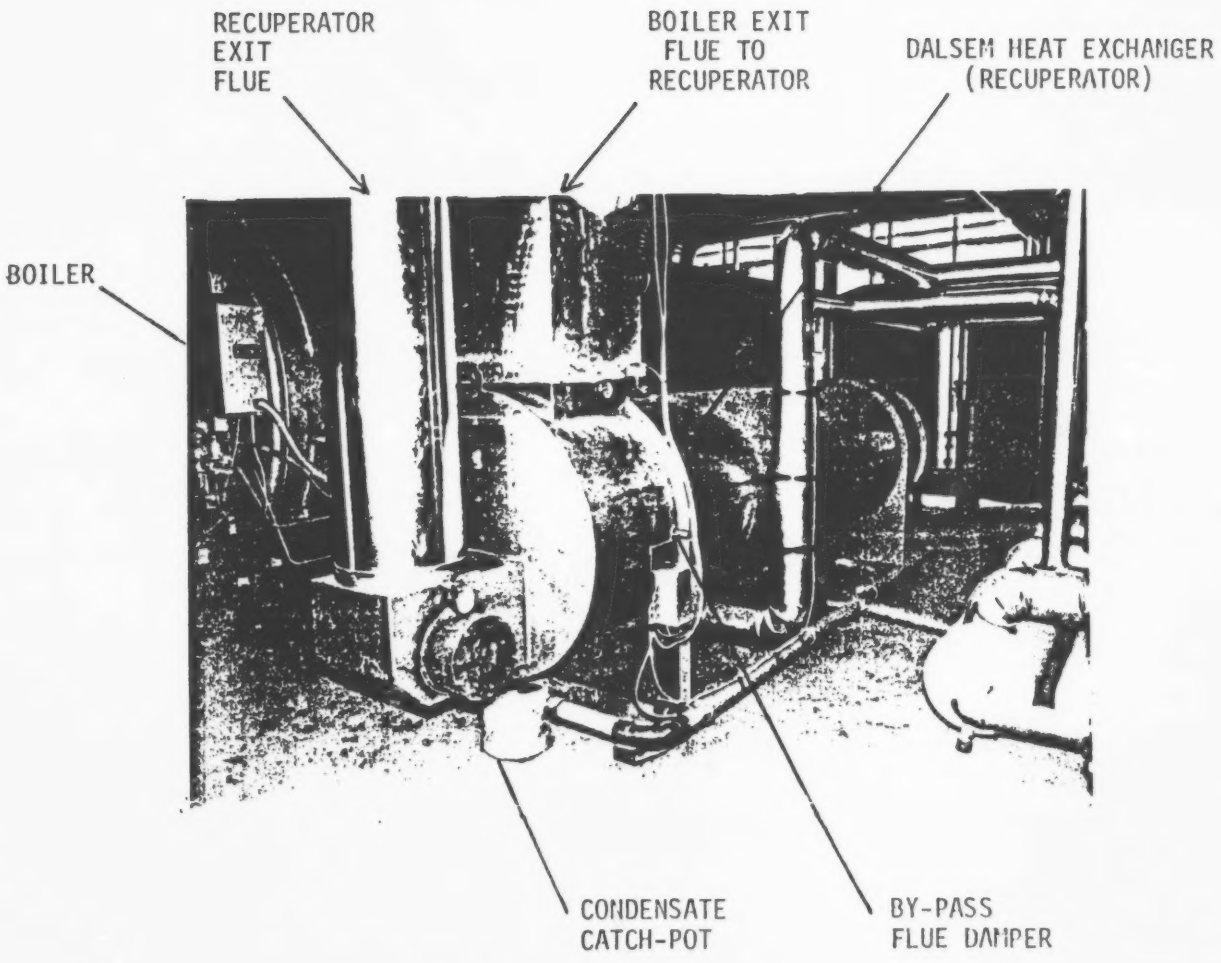

RECUPERATOR
EXIT
FLUE
BOILER EXIT
FLUE TO
RECUPERATOR
DALSEM HEAT EXCHANGER
(RECUPERATOR)
BOILER
CONDENSATE
CATCH-POT
BY-PASS
FLUE DAMPER

Figure 1

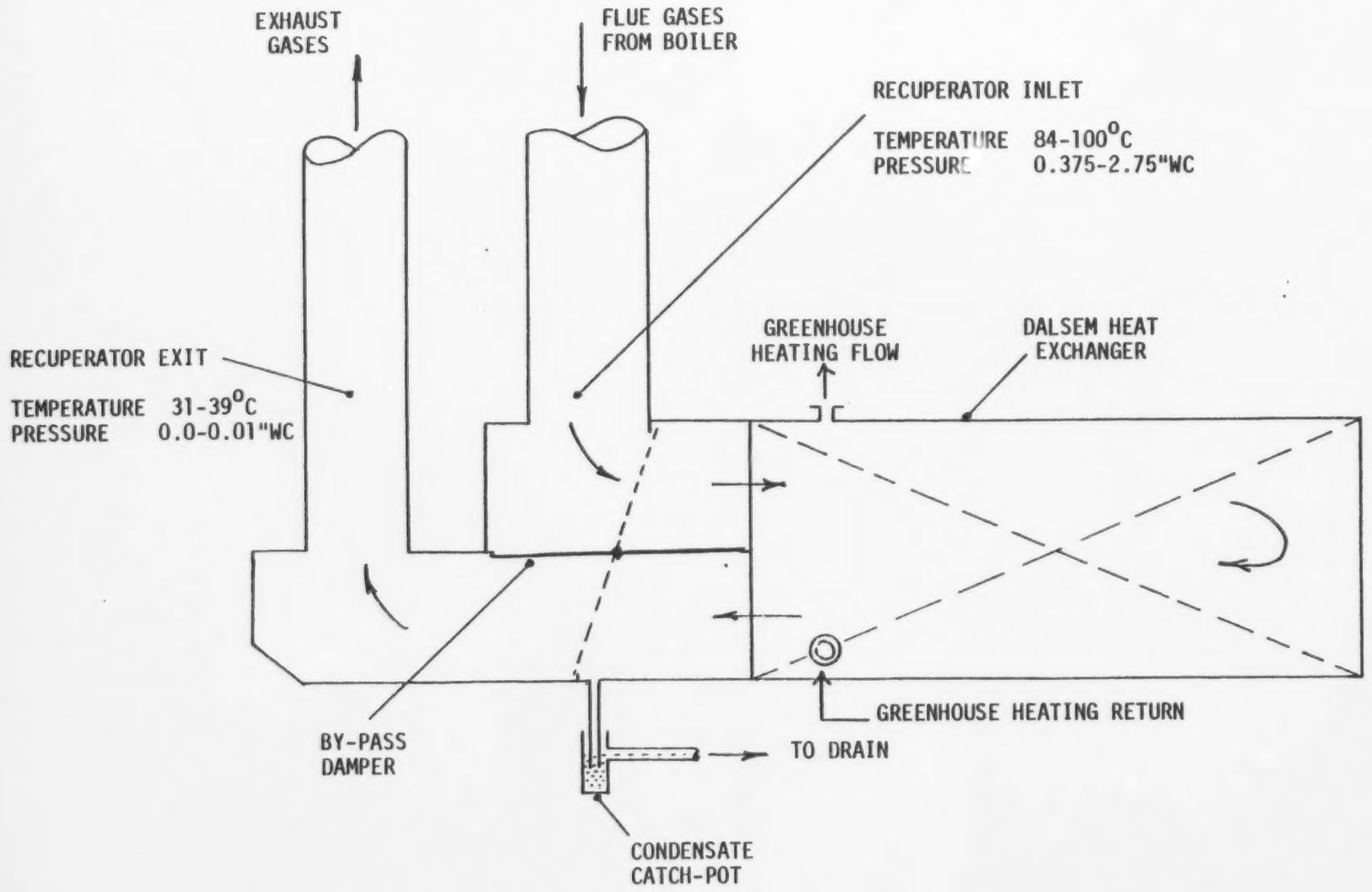

EXHAUST GASES
FLUE GASES FROM BOILER
RECUPERATOR INLET
TEMPERATURE 84-100°C
PRESSURE 0.375-2.75"WC
RECUPERATOR EXIT
TEMPERATURE 31-39°C
PRESSURE 0.0-0.01"WC
GREENHOUSE HEATING FLOW
DALSEM HEAT EXCHANGER
GREENHOUSE HEATING RETURN
BY-PASS DAMPER
TO DRAIN
CONDENSATE CATCH-POT

Figure 2

Flue gas pressures were taken at the heat exchanger flue gas entrance and outlet.

6. TEST RESULTS

The results are tabulated on page 8.

There was a water temperature rise across the heat exchanger of 9°C (16°F) at High Fire. As water flow rate measurements were not taken, this figure is of little value, except to indicate that heat transfer was taking place.

The excess air levels were calculated from the CO_2 values, and the flue losses were derived from the excess air and flue gas temperatures. The recuperator stack loss included for the latent heat of condensation.

The boiler shell loss was taken as 1% of the gross thermal input at 100% rating (manufacturer's published data). As the quantity of heat lost from the shell is almost independent of firing rate, the shell loss expressed as a percentage of the fuel input was pro-rated for other firing rates, .

The total loss is the sum of the flue loss and boiler shell losses. The Fuel-to-Water Efficiency was then obtained from the difference between the thermal input and the total losses at a particular firing rate. Hence:

Fuel-to-Water Efficiency = 100% - (Flue Loss + Shell Loss)%

Fuel saving, expressed as a percentage of fuel input, is based on the formula:

$$\% \text{ Fuel Saving} = \frac{\text{Improvement in Efficiency} \times 100}{\text{Original Efficiency}}$$

7. DISCUSSION OF RESULTS

7.1 Efficiency and Energy Savings

Combustion efficiency at the boiler exit (100 - Boiler Flue Loss)% was above 80% - an acceptable level. The absence of CO at High Fire and only a trace of CO at Low Fire indicated that the recuperator did not impede the combustion process.

The combustion efficiency at the recuperator outlet (100 - Recuperator Stack Loss)% is above 90% - an acceptable figure.

The recuperator resulted in a reduction in the flue loss from 10.4 to 10.5% for estimated savings of between 12.5 and 12.9% of the fuel input (12.7% average), depending on the firing rate.

Such a reduction in flue loss and estimated savings are of the order expected.

Estimates of energy savings are best made from a full year's gas consumption records. In the absence of these data, however, an approximation of savings may be made using the averaged annual energy consumption per unit area for greenhouses in the Fraser Valley.

Records show that the natural gas consumption for heating greenhouses in the Fraser Valley is approximately 1.7 GJ/m².year without heat recovery. With heat recovery, the consumption would be some 1.5 GJ/m².year.

The calculated annual gas use for Mr. van Marrewyk's greenhouse is thus: 11 300m² (estimated area) x 1.5 GJ/m².year = 16 950 GJ/year.

Annual saving: 16 950 GJ/year x 12.7% = 2 153 GJ/year
Annual avoided cost: (2153 GJ/year x $4.14/GJ) + 7% B. C. Sales Tax = $9537/year (or $9500/year approximately)

The installed cost of the recuperator was reportedly $13,000 approximately, giving a simple payback on the investment of some 1.4 years.

7.2 Pressure Drop

At High Fire operation and with the recuperator on by-pass, the exhaust gas pressure drop across the by-pass 0.5"WC - sufficient to reduce the boiler's maximum input to about 93% of the rated value.

When the heat recovery system was in operation, the exhaust gas pressure drop across the recuperator was 2.75"WC at High Fire and the boiler's maximum rated input was reduced to 81% of the rated value. However, the reduction in input capability was partiall offset by an increase of some 12.5% of output due to efficiency gain.

Thus, the net result of the recuperator installation was to reduce the rating of the boiler from 100% to abcut 91% (81% + (81% x 0.125)). This reduction is to be expected in view of the relatively high pressure drop (about 2.75"WC) across the flue system under High Fire conditions.

The reduction in rating could become a problem should the greenhouse's heating system require the full manufacturer's rated capacity of the boiler. (It is understood that the boiler under discussion is presently oversized.)

The output of the boiler/recuperator combination could be increased by:

Either 1. Modifying the existing gas burner system to operate with sufficiently high combustion air pressure. (Preferred method.)

Or 2. Installing an induced draft fan at the boiler outlet.

Either of the above changes would require Provincial Gas Inspector approval.

7.3 Corrosion

It is understood that there is no evidence of corrosion to-date. If practicable, an inspection of the heat exchanger surface should be made after about a year's operation.

ACKNOWLEDGEMENTS

B. C. Hydro wishes to thank Mr. Albert van Marrewyk for his cooperation and help throughout this project.

The assistance of the Industrial Services Section of the Fraser Valley Gas Division and C. L. Dyble, Agricultural Specialist for B. C. Hydro's Lower Mainland Division, is gratefully acknowledged.

TABLE OF RESULTS
TEST ON DALSEM HEAT EXCHANGER (RECUPERATOR)
A. VAN MARREWYK GREENHOUSE, 13444 McKECHNIE RD, PITT MEADOWS, B. C.

DATE OF TEST: 9 January 1985
BOILER DATA: Cleaver-Brooks 200-350 Hot Water
Rated Input: 14,650,000 Btu/h
HHV GAS: 39.35 MJ/m³ = 1,057 Btu/ft³

	UNITS	Flue Gases Through Recuperator		Recuperator By-Passed
		Low Fire	High Fire	High Fire
Combustion Air Temperature	°C(°F)	6(43)	2(36)	6(43)
Boiler Exit				
CO_2	%	6.0	7.5	7.25
Excess Air	%	86.9	51.7	56.5
CO	ppm	trace	0	0
Temperature	°C(°F)	84(183)	100(212)	100(212)
Pressure	"WC	0.375	2.75	0.5
Recuperator Exit				
Temperature	°C(°F)	29(84)	31(88)	100(212)
Pressure	"WC	0.0-0.01	0.0-0.01	0.0-0.01
Gas Rate	ft^3/h	4,290	11,210	12,930
Heat Input	10 Btu/h	4.535	11.850	13.665
Rating	%	31.0	80.9	93.3
Boiler Shell Loss	%	3.2	1.2	1.1
Boiler Flue Loss	%	15.4	15.3	15.4
Recuperator Stack Loss	%	4.9	4.9	N/A
Fuel-to-Water Efficiency before Recuperator	%	81.4	83.5	83.5
Fuel-to-Water Efficiency with Recuperator	%	91.9	93.9	N/A
Estimated Savings (fuel input basis)*	%	12.9	12.5	N/A

*Estimated Savings = $\frac{\text{Improvement in Efficiency}}{\text{Original Efficiency}}$ x 100%

Specification of the flue gas condensor.

Flue gas duct	: 4 mm St 37
Frontplate	: 6 mm cortênsteel
Shell	: 5 mm cortênsteel
Tube plate	: 10 mm St 37
Tubes	: 1 1/4" welded gas pipe

Flue gas resistance in the condensor: 40-50 mm head of water.

The flue gas condenser is constructed according to the counterflow principle.
The flue gas passes through the pipes and the surrounding water flows in the opposite direction.

All surfaces, which are in contact with the flue gas or condensate are protected with an epoxy tar coating.

The fronts are detachable, so that good inspection and cleaning are possible.

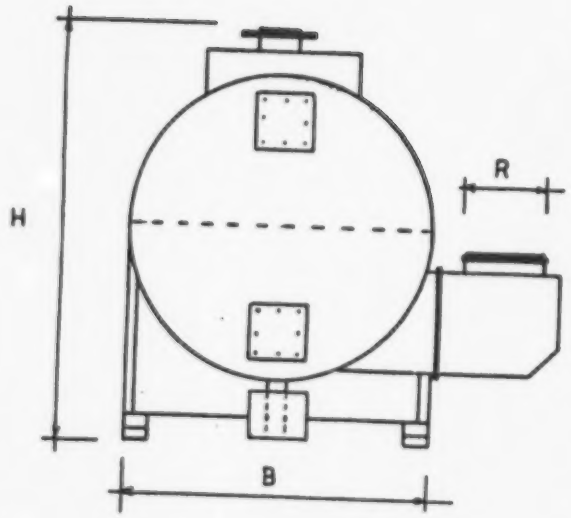
General information

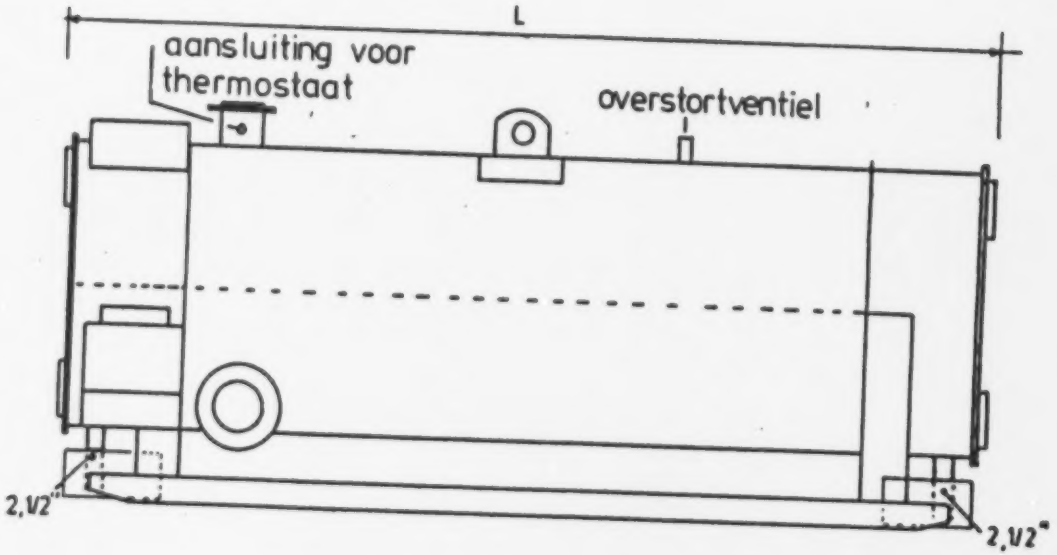
The flue gas condenser is installed near the boiler, and can be shut off from the boiler by flue gas valves.

The function of the flue gas condenser is to cool down the flue gas of the boiler from ± 180° Centigrade (356° F) to 40° Centigrade (104° F).
This depends on the return watertemperature of the heating system.

By doing this both the perceptible heat as well as the heat of the condensate can be used.

Heat of condensation is generated when the flue gas cool down below 59° Centigrade (138° F)

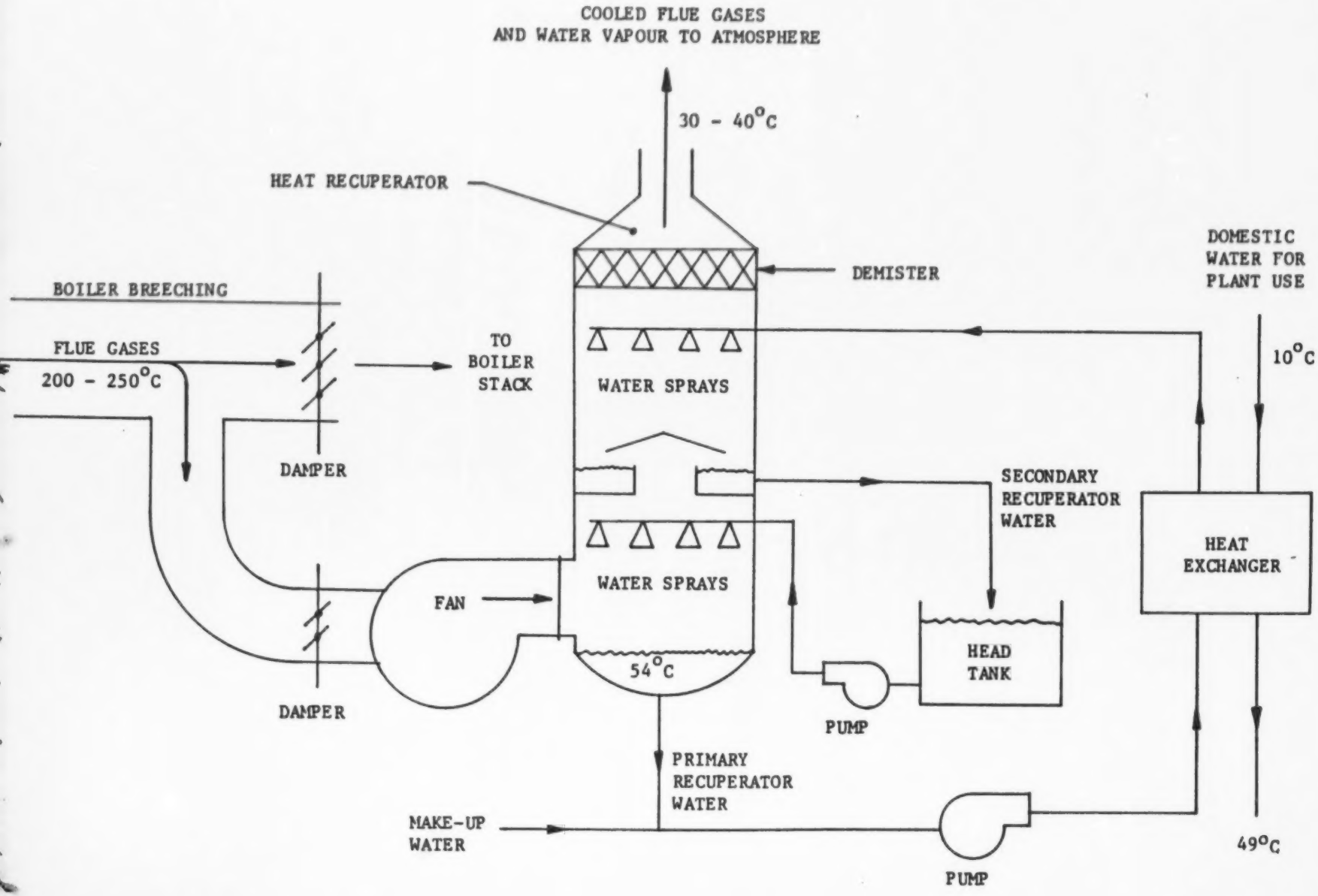


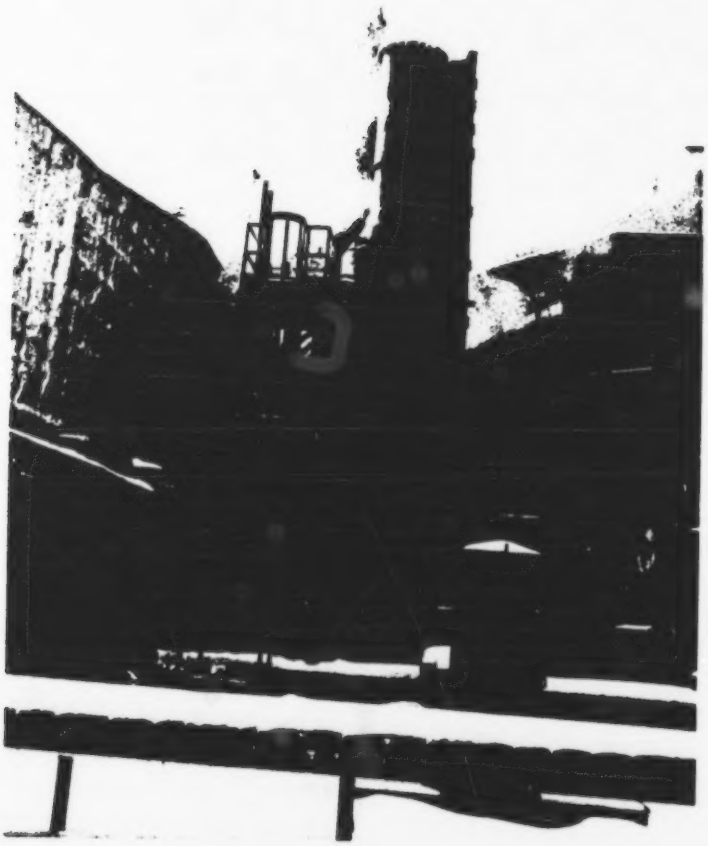


type	C 100	C150	C 200	C 250	C 300	C 400	C 500
ketel capaciteit in Gcal/h	1	1,5	2	2,5	3	4	5
totale lengte L	4000	4000	4000	4000	4000	4000	4000
totale breedte B	760	880	1050	1130	1250	1390	1540
totale hoogte H	1160	1280	1450	1530	1650	1700	1940
gewicht	1487	2295	2865	3590	4235	5358	6900
m^2 V.O.	40	60	80	100	120	160	200
diam. aanvoer en retour	80	100	100	100	100	125	125
rookgasuitlaat R	300	400	400	450	450	500	500

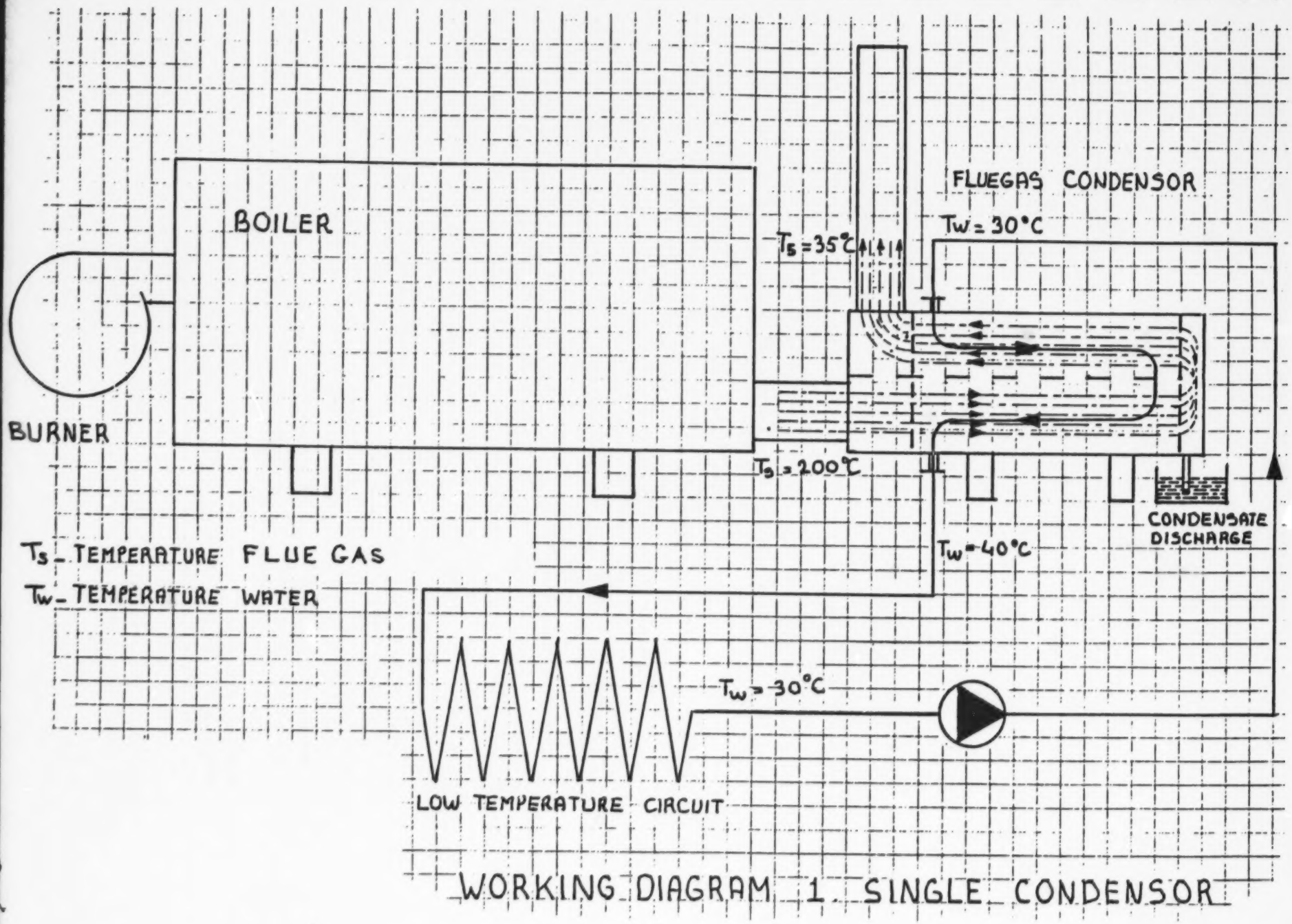
APPENDIX C - Flow Diagram and Equipment Photograph for Direct Contact Flue Gas Condensation Heat Recovery System at Site No. 3.

THURLEY DIRECT CONTACT RECUPERATOR

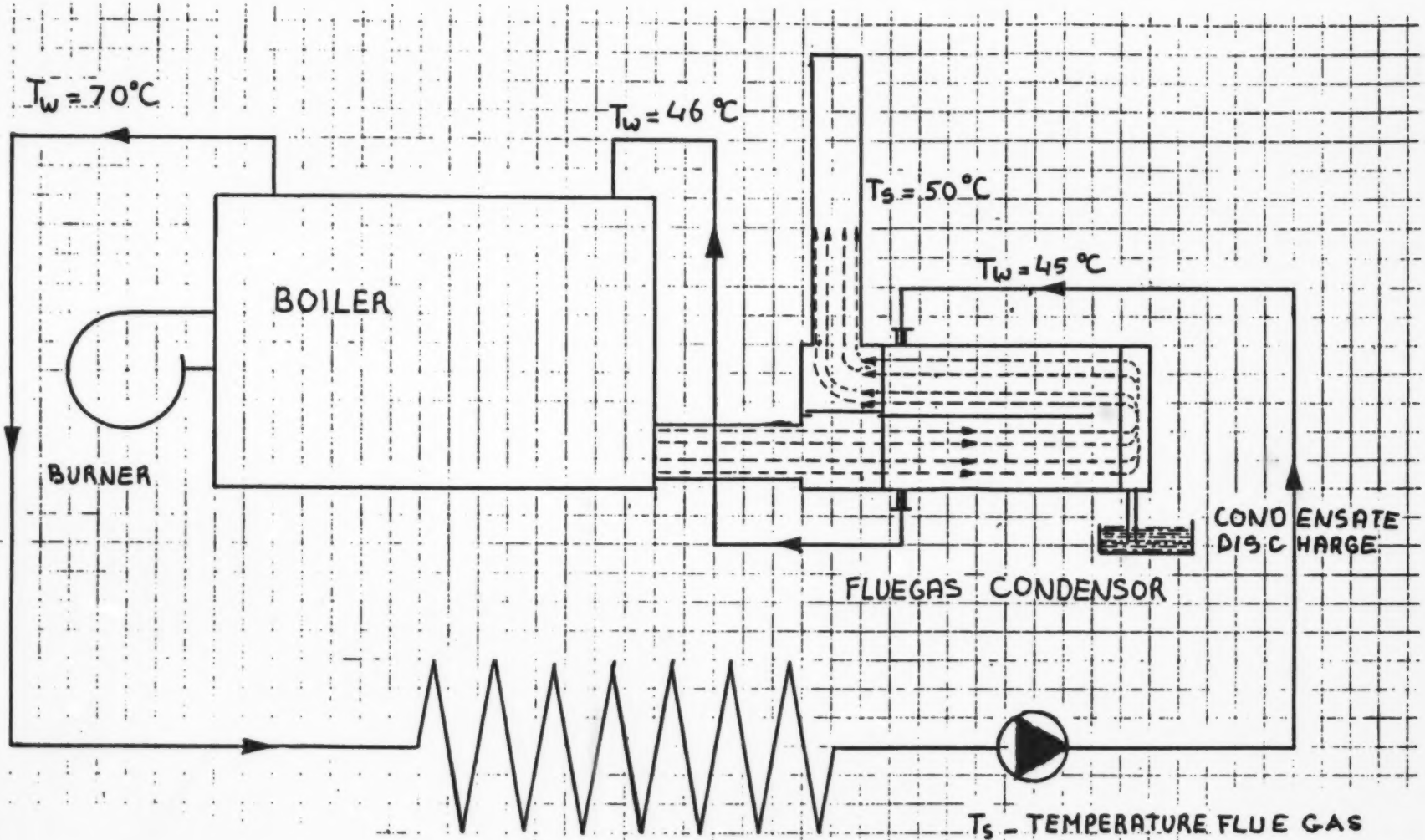




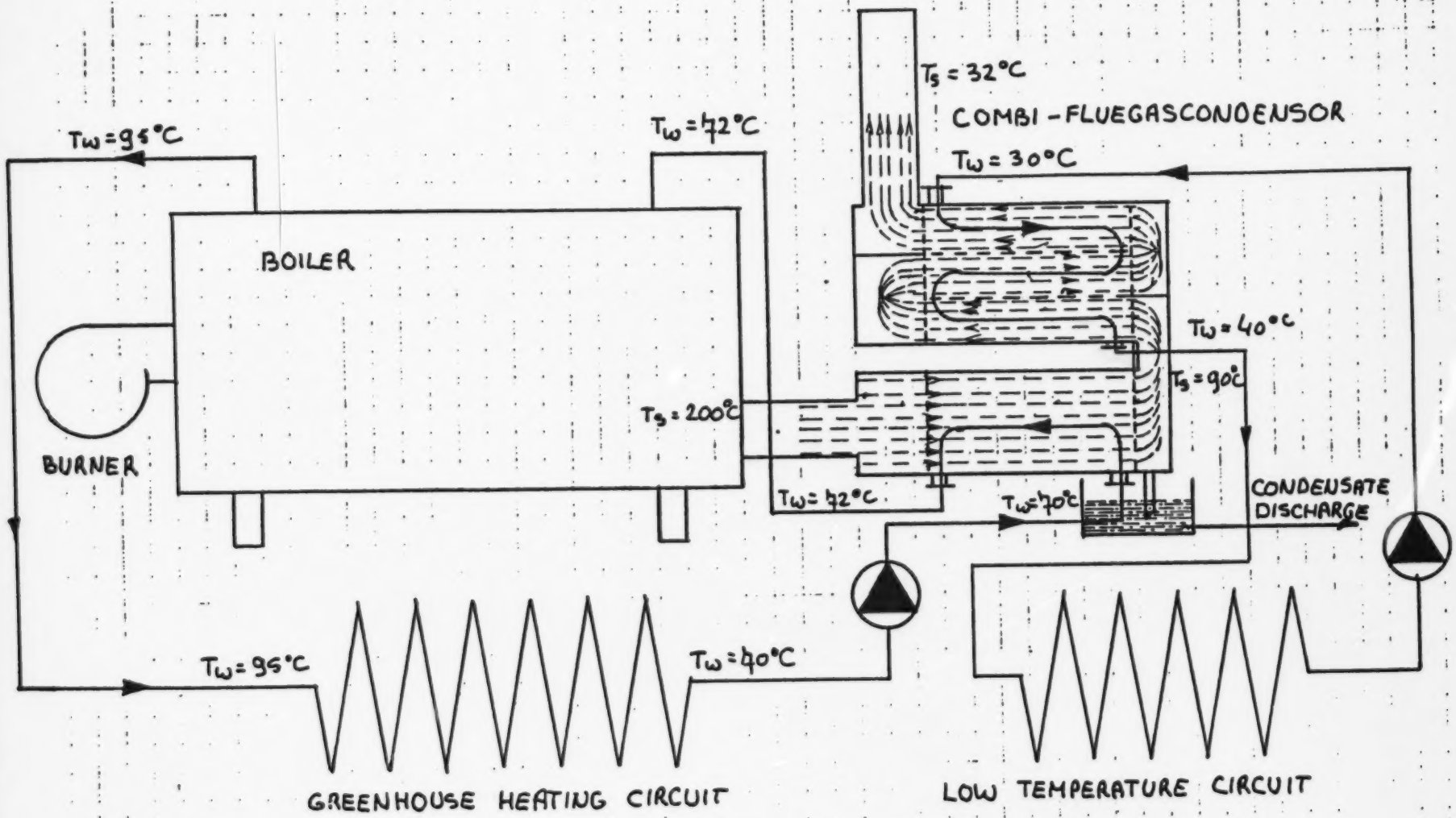
APPENDIX D - Typical Water Heating Circuits for Surface Flue Gas Condensers



WORKING DIAGRAM 1. SINGLE CONDENSOR



WORKING DIAGRAM 2. CONDENSOR IN RETURNLINE



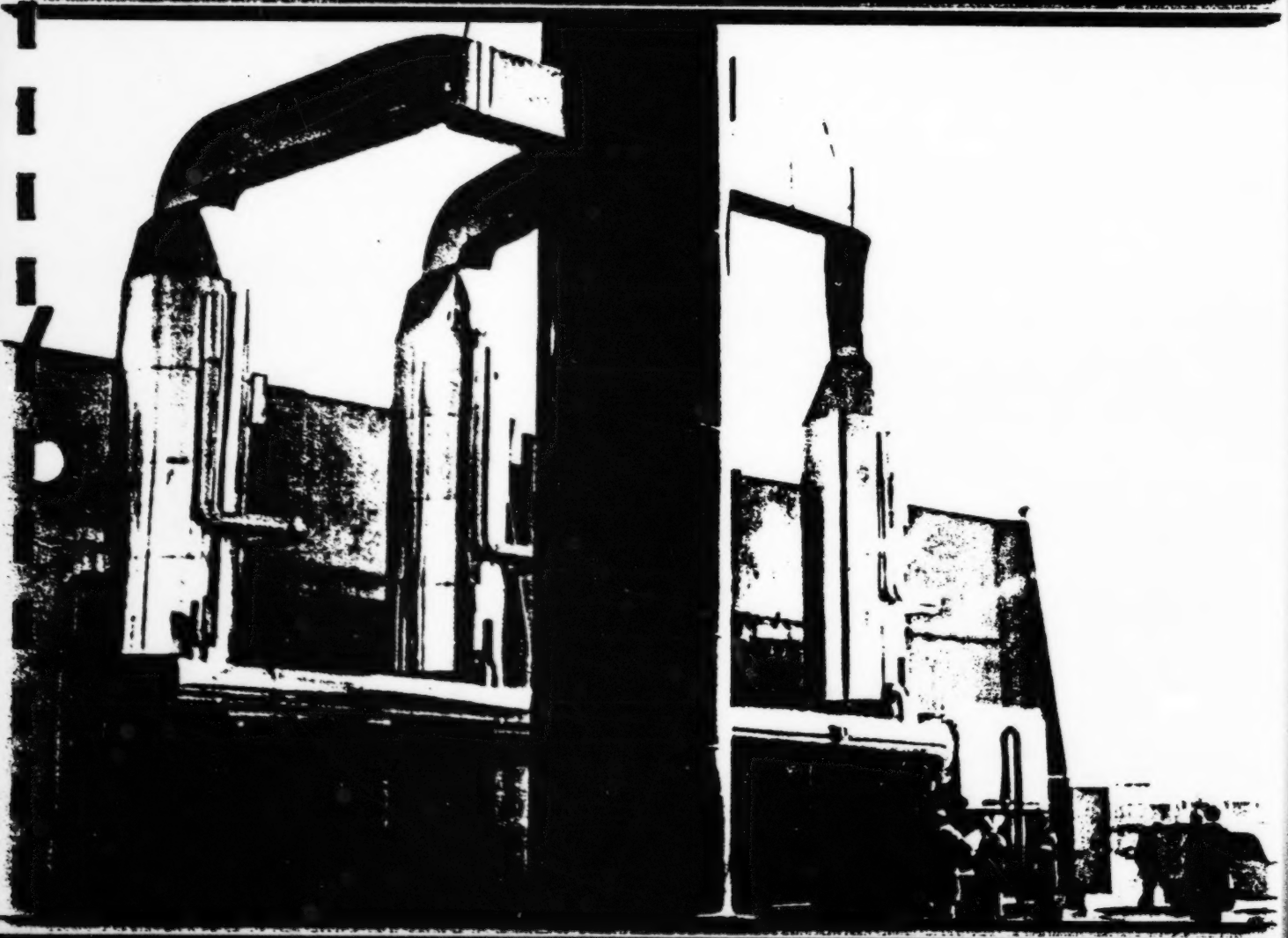
T_s - TEMPERATURE FLUE GAS

T_w - TEMPERATURE WATER

WORKING DIAGRAM 3. COMBI_CONDENSOR

APPENDIX E - Direct Contact Flue Gas Condenser as Marketed by Rocket Research Company

·ONBOARD [illegible] MANAGER · CHECK



[illegible] RESEARCH COMPANY
ROCKET

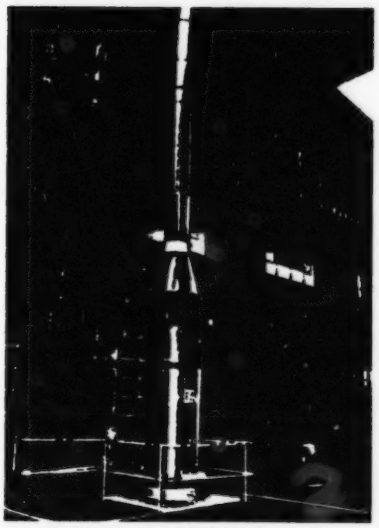
Natural gas-fired equipment such as boilers, water heaters, dryers and furnaces, exhaust 15—20% or more of the fuel energy they consume in the form of medium-to-high temperature flue gas, even though air-preheaters and economizers may be used. The patented CONDENSING HEAT EXCHANGER (CHEX), manufactured in the U. S. and Canada by ROCKET RESEARCH COMPANY under license from L'INDUSTRIELLE de CHAUFFAGE, is designed to ***cut operating costs*** by recovering much of this heat normally lost to the atmosphere. When this recovered heat is used, ***savings of 12—16%*** in primary energy use and operating cost are typical. The effectiveness of these units has been proven time and again in dozens of operating installations.

OPERATION

- **Sensible heat recovery**
- **Latent heat recovery**
- **Baffle-type**
- **High efficiency**

The CONDENSING HEAT EXCHANGER recovers heat losses by cooling flue gases adiabatically, i.e., by spraying water directly into the hot gas and reducing its temperature below the dew point. This direct contact deliberately induces condensation inside the unit, which provides a continuous hot-water product containing both sensible heat from the flue gases and the latent heat content of the now-condensed water vapor.

In the CONDENSING HEAT EXCHANGER, hot flue gases are introduced near the bottom of the unit and flow upward counter to a series of water curtains. Baffles arranged internally cause the gas to change direction several times, crossing and recrossing the water curtains, thus ensuring intimate contact and high recovery efficiency. Gases exit in a saturated condition at the top of the unit at a temperature equal to the exiting product water temperature. Hot water is removed from the base of the unit to a constant-level tank where an amount equal to the moisture condensed is continuously sewered to maintain a constant water volume in the system. The hot water



An industrial drying application in Albine, France

is then normally pumped through a plate-type secondary heat exchanger which removes the recovered heat to a potable or treated user water supply. Alternatively, the slightly acidic (normally pH 5.5 or higher) hot water may be used directly where water quality standards or subsequent treatment permit.

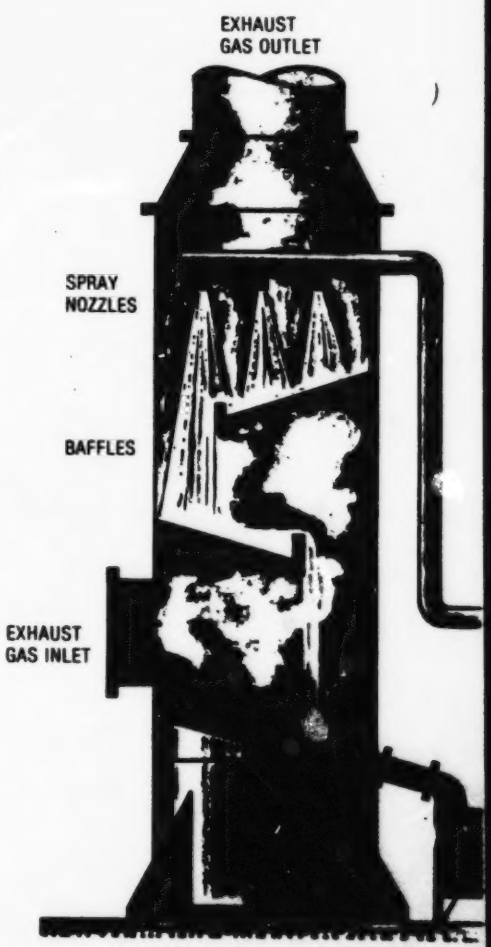
Typically, flue gases of 350°F or higher will be cooled to 100°—120°F. Hot water is then collected at 100°—120°F. The curve at the right shows the heat that may be recovered from a boiler flue gas temperature of 425°F. When these gases are cooled, for example, to 105°F, the recovered heat amounts to 15% of the high heating value of the fuel and provides an effective boiler efficiency of 94.1% HHV. Lower use temperatures result in higher heat recovery and higher efficiency, thus making preheating applications extremely effective.

INSTALLATION

- **Natural gas & dual fuel**
- **Simple, low maintenance**
- **Low back pressure**

The CONDENSING HEAT EXCHANGER is fabricated from AISI 316L stainless steel and is designed primarily for application to natural gas or dual-fuel systems. In dual-fuel systems, the water spray is not operated when oil firing to avoid system corrosion from excessive sulfuric acid condensation.

Installation of the CHEX is simple, requiring only mounting support for the recuperator and tank, plastic or steel piping interconnection of these components with the pump and secondary heat exchanger (if used), pump-power hookup, and ducting to lead the exhaust gases to the recuperator. If the existing stack is to be maintained or for multiple boiler installations on a single recuperator, dampers are also used in the gas ducts. The equipment can be dispersed to convenient installation locations or can be skid mounted in a compact package.



CONDENSING HEAT EXCHANGER — CHEX

The CONDENSING HEAT EXCHANGER ***operates unattended***, and requires ***little maintenance***. Periodically, screen filters in the constant-level tank require washout, and the water pH is checked for excessive acidity which is simply controlled by dilution.

The CHEX presents approximately 1-inch-water back pressure to the gas appliance. In most cases, this low back pressure will allow installation without the use of a fan. Where an ID fan is required, power requirements are low due to the low exit gas temperature.

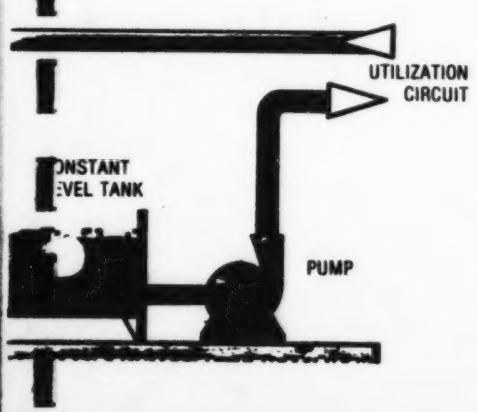
A variable user load is readily accommodated by the CHEX, including the limiting case of no-load.

USES

- **Space comfort heating**
- **Domestic water heating**
- **Preheating makeup water**
- **Preheating combustion air**
- **Swimming pool heating**
- **Greenhouses**
- **Process water**

To realize an efficiency gain, the recovered heat must be put to use. Heat recovered by the CONDENSING HEAT EXCHANGER may be used for a variety of purposes, depending on the user circumstances. Space comfort heating and domestic water heating are two primary uses. Additional uses include: preheating of boiler make-up water, combustion air, laundry washwater, industrial process water, product stream, and fuel tanks (e.g., No. 6 oil). Heating of swimming pool water and greenhouses has found wide application as have certain drying operations.

The CHEX is well suited to industrial use as well as commercial/institutional applications. Numerous uses are found in food, textile, beverage, tobacco, lumber, leather, fermentation, pulp/paper, chemical and other industries. Schools, hospitals, government buildings, laundries, laboratory and research centers, swimming pools, greenhouses, hotels, and central district heating systems will all benefit significantly from the use of this equipment. The CHEX is cost effective whether installed as (1) a retrofit to an existing system, (2) as part of a new system, or (3) when designed for partial recovery up to the limit of the use for the heat.



Heat Recuperated

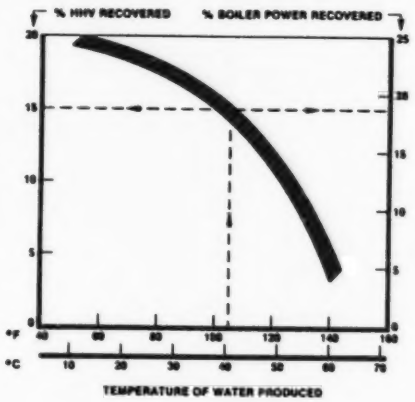
NATURAL GAS COMBUSTION —
HHV 23,113 Btu/lb

FLUE GAS TEMPERATURE — 425°F

EXCESS AIR — 20%

STANDARD COMBUSTION AIR —
0.013 lb WATER/lb DRY AIR

BOILER EFFICIENCY BEFORE RECUPERATION—
79.1% HHV



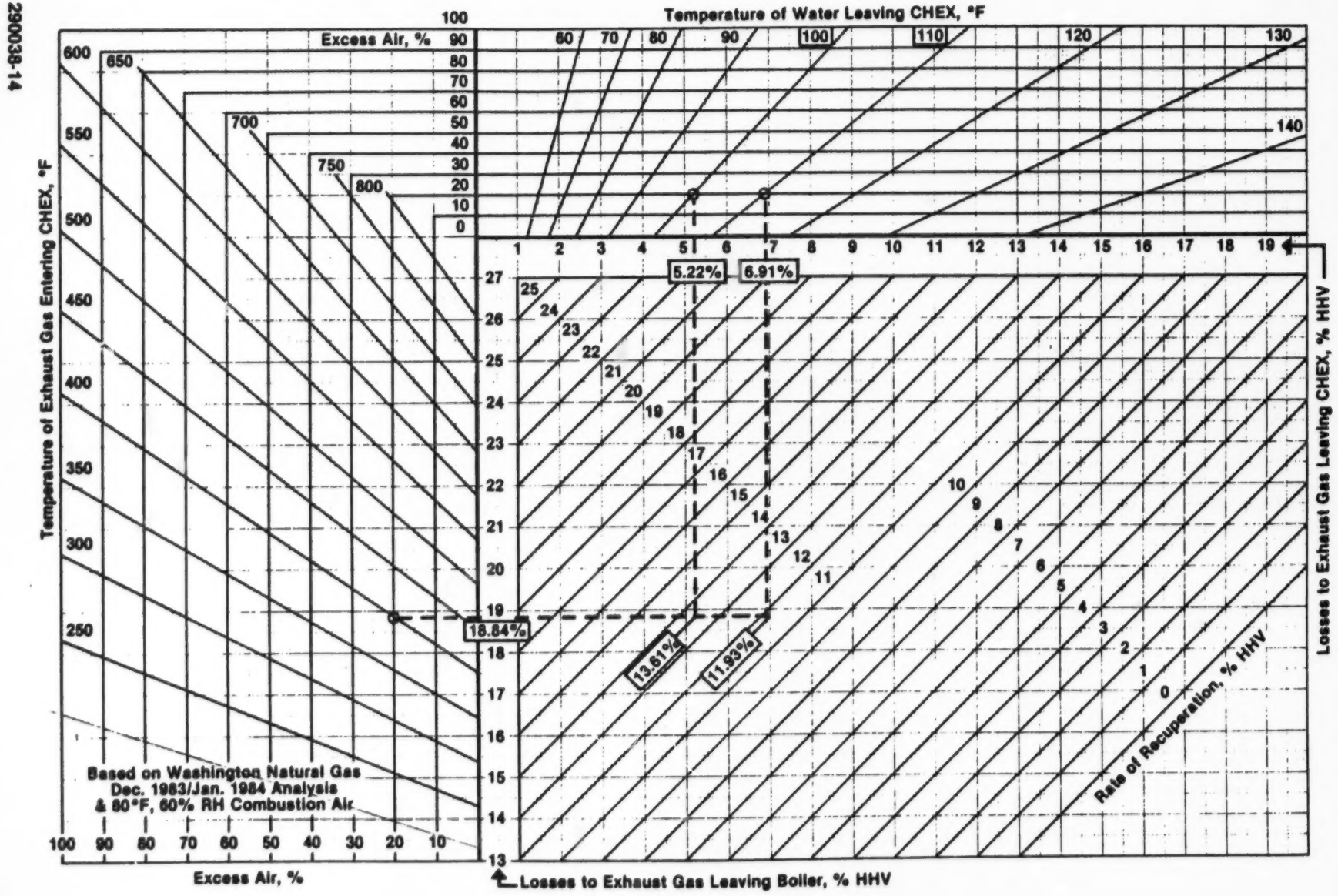
BENEFITS

- **Increased system efficiency (Typ. to 92—95% HHV)**
- **Cost savings (Typ. 12—16%)**
- **Short system payback (Typ. 9—18 mos)**
- **Easy installation, low maintenance stainless steel construction**
- **Reduced particulate & noxious gas emissions**
- **Substantial reduction in water-vapor emissions**
- **Reduced noise emission from the stack**
- **Accommodates wide fluctuations in operating conditions**
- **Low back-pressure (~1.0 in WC)**

The savings from installation of a CONDENSING HEAT EXCHANGER may be realized several ways. Direct savings in fuel use and cost is found, for example, through reduction in the number or power level of existing boilers. Similarly, increased boiler-room energy availability at present fuel use levels can delay or offset the need for new capacity and avoid bringing cold boilers on line at partial power levels. When several boilers are coupled to a single CHEX, additional savings of several percent are obtained by draft reduction and recovery of cool-down losses.

Let us examine your application now. Call or write us with a description of your heat source and potential energy uses, and we will be happy to tell you what CHEX can do to upgrade your facility and reduce your operating costs.

CHEX Recuperator Performance with Natural Gas-Fired Boiler



APPENDIX F - Illustrations of Surface Flue Gas Condensers Available from Holland

SUMMARY OF CHARACTERISTICS OF FLUE GAS CONDENSERS

PROPOSED BY DUTCH MANUFACTURERS

MANUFACTURER	BOILER	CONDENSER TYPE	MATERIALS OF CONSTRUCTION SHELL	TUBE SHT.	TUBES	FINS	SURFACE AREA m^2(1)	PRICE $(2)	WEIGHT KG
Thermeta	Superhot	water-tube	--- All Aluminum ---		57s --------		78 (g.s.)	6,000.	
	Cleaver-Brookes	water-tube	--- All Aluminum ---		57s --------		36 (g.s.)	4,433.	
Enalco	Superhot	gas-tube	Alum.	Alum.	Alum.	(3)	14.0 (w.s.)	3,995.	
	Cleaver-Brookes	gas-tube	Alum.	Alum.	Alum.	(3)	5.2 (w.s.)	2,693.	
Crone	Superhot	gas-tube	-- Epoxy coated steel on --			None	27 (w.s.)	4,977.	910
	Cleaver-Brookes	gas-tube	-- gas side -steel on water side			None	12 (w.s.)	3,628.	540
Dalsem	Superhot	water-tube	- Not specified -		316ss	Alum.	85 (g.s.)	32.572	340
	Cleaver-Brookes	water-tube	- Not specified -		316ss	Alum.	26 (g.s.)	6,878	160

(1) g.s. - gas side, w.3 - water side

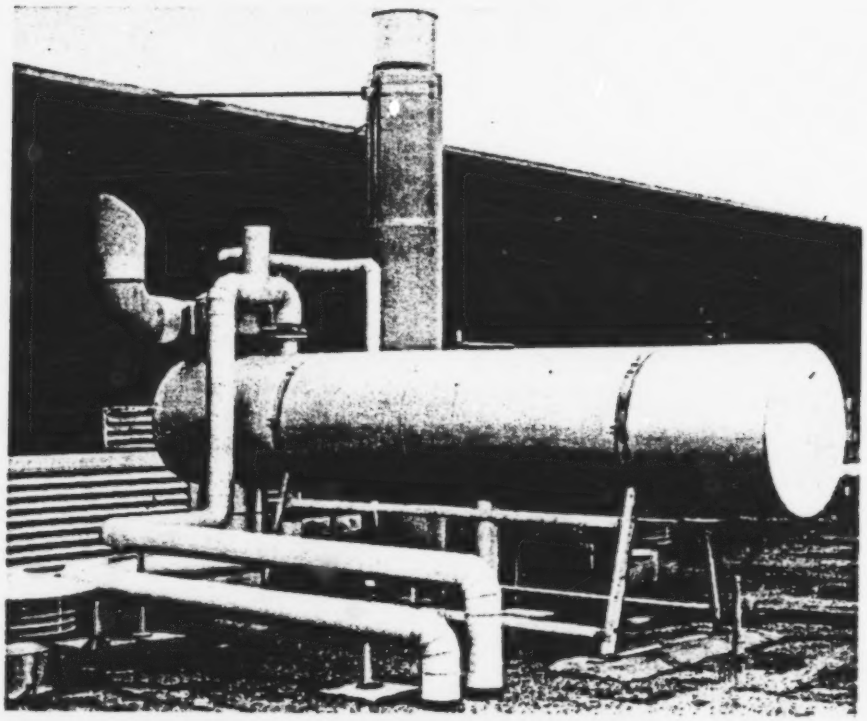
(2) Prices exclude freight, duty, and taxes and are at a conversion rate of 1 guilder=$0.507

(3) Longitudinal fins on insides of tubes.

Note: For configurations of above condensers, see Appendix E.

ENALCO B.V. Rijsenburgerweg 24a - Postbus 21 - 2685 ZG Poeldijk - Tel. 01749-46512

Aluminium Rookgascondensors



ROOKGASCONDENSOR BETEKENT ENERGIEBESPARING

- **GROTE BESPARINGEN**
- **HOGE WERKINGSGRAAD**
- **GESCHIKT VOOR IEDERE CAPACITEIT**
- **STANDAARDPROGRAMMA TOT 8 Mcal/H**
- **ERVARING IN TUINBOUW EN INDUSTRIE**

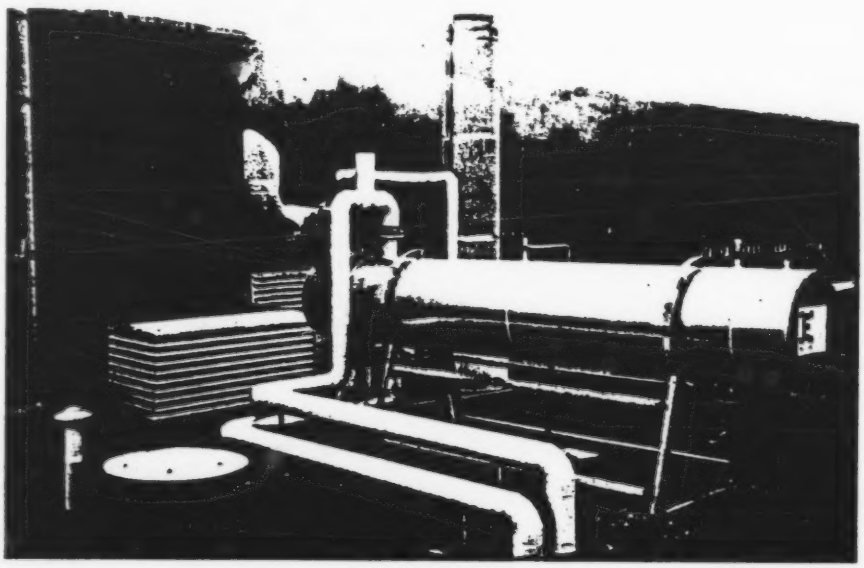
ENALCO B.V. Rijsenburgerweg 24a - Postbus 21 - 2685 EB Poeldijk - tel.: 01749-46512

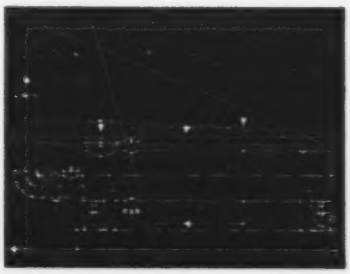
Aluminium Rookgascondensors

ENERGIE-BESPARING
door het toepassen van een aluminium ROOKGASCONDENSOR

Systeem:
warm/heet waterver-gebruik.
Dit systeem is vooral van groot belang voor bedrijven en instellingen, die *veel* stoom en/of heet water ver-gebruiken, zoals:

- Voedingsmiddelen-industrie
- Melkindustrie, slachterijen
- Wasserijen
- Ziekenhuizen
- Zwembaden
- Verwarming van kantoren
- Tuinderijen

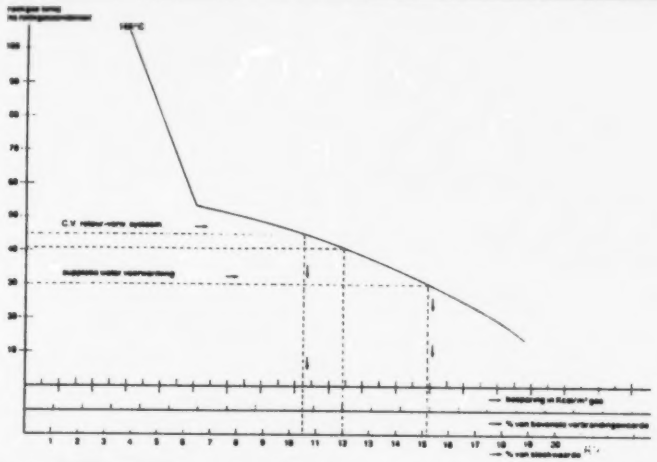


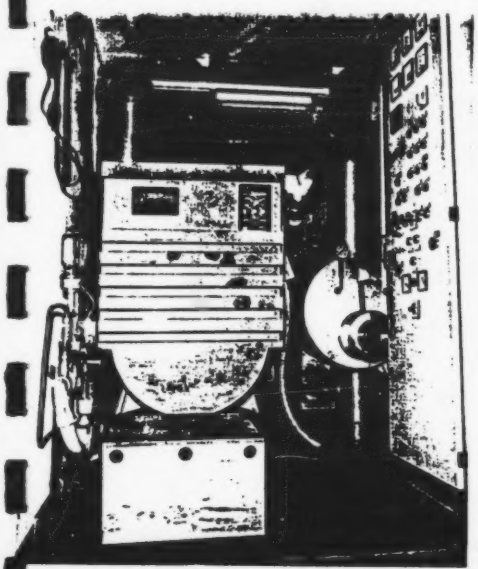


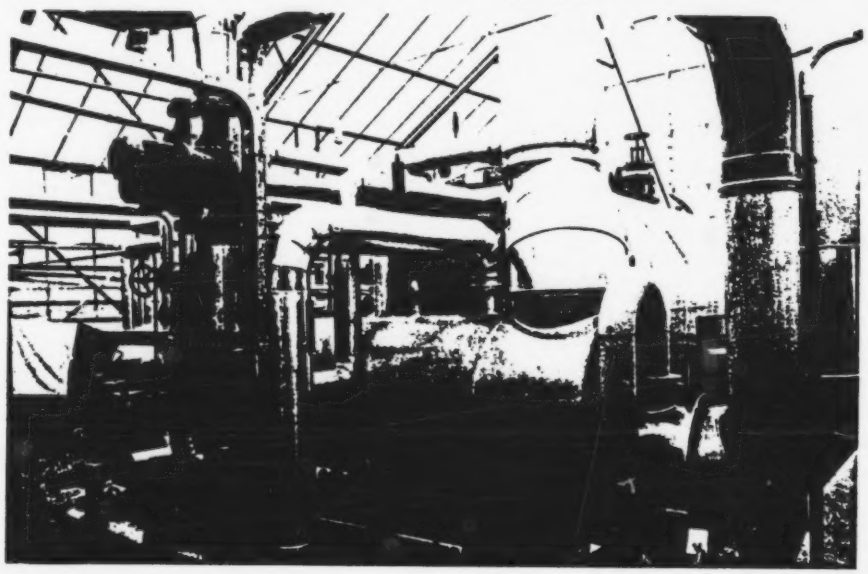
WERKING
Met behulp van de condensor kunnen rookgassen, van een nieuw te bouwen of bestaande installatie, tot bijv. 30-50 °C worden afgekoeld, waarbij water wordt opgewarmd van bijv. 20 °C naar 60 °C.
Daarbij komt, naast de voelbare warmte, beneden de 58 °C (dauwpunt van de rookgassen) ook de zgn. latente warmte van de in de rookgassen aanwezige waterdamp door condensatie, beschikbaar voor gebruik. Op deze wijze zijn brandstofbesparingen tot 20% bereikbaar.
Door de keuze van het hoogwaardige materiaal zijn bij zwavelarme brandstoffen geen corrosie-problemen te verwachten.
Er zijn rookgascondensors beschikbaar voor ketels van: 350 kW (250.000 Kcal/h)
9000 kW (10 milj. Kcal/h)
(of meer)
Een gemodificeerde versie is ontwikkeld voor Total Energy installaties, waarbij t.o.v. de normale afgassenketel een aanzienlijke extra warmte-opbrengst gerealiseerd wordt.

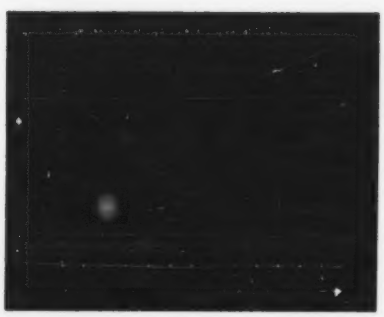
Aluminium Rookgascondensors

VOORBEELD
Rookgastemp. voor condensor:
180 °C na 45 °C
CO_2% (droog) 9% rendement met condensor: 90,7% (Hb)
Rendement zonder condensor:
81,2% (Hb)
BESPARING CA. 10%
OP STOOKKOSTEN









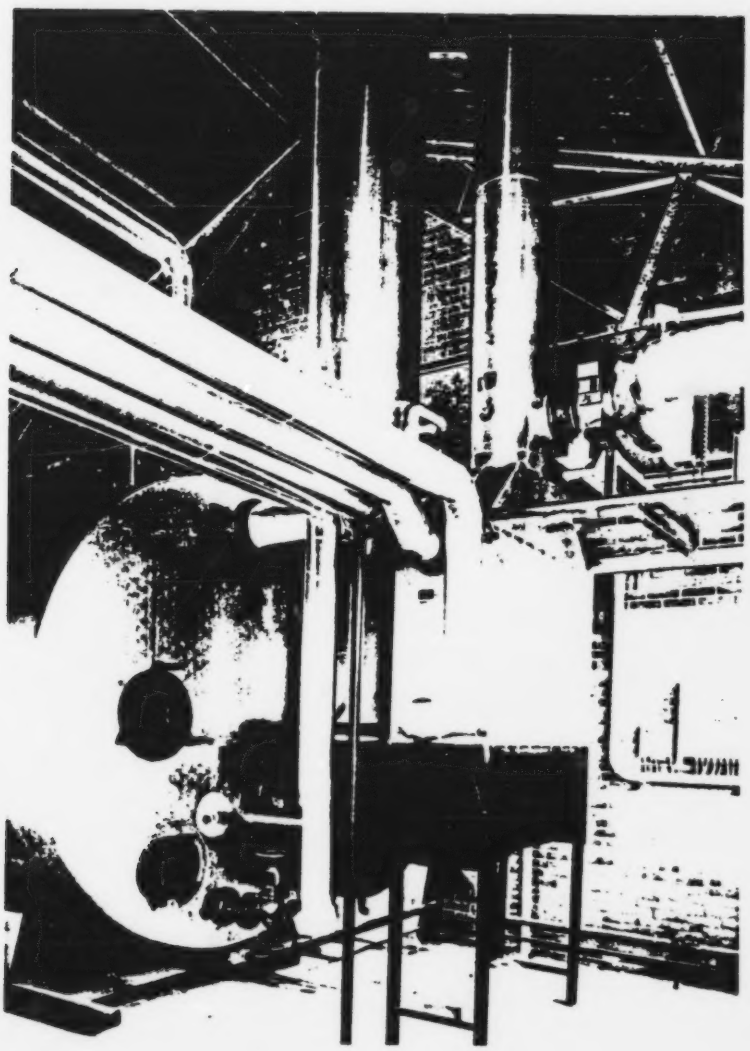
VOORDELEN
- Energiebesparing tot 20% mogelijk
- Economisch verantwoorde investering
  Pay-out vaak binnen 2 jaar
- Garantie op corrosie-bestendigheid
- Geen onderhoud
- Zeer bedrijfszeker
- Slechts geringe aanpassing bestaande systemen noodzakelijk
- Geen stoomwezenkeuring

BEPERKINGEN
- Maximale opwarmtemperatuur:
  99 °C
- Maximaal toelaatbare werkdruk:
  3,5 bar
- Zwavelarme brandstoffen (aardgas)
- Voor ketels van:
  350 kWh (250.000 Kcal/h)
  9000 kWh (10 milj. Kcal/h)
- Voor Total Energy-installaties
  vanaf 80 kW.

Wij zijn gaarne bereid U nader te adviseren omtrent de technische- en verantwoorde toepasbaarheid van onze rookgascondensor(s).
Voor meer informatie is één telefoontje voldoende.

ROOKGASCONDENSOR
COMBI-CONDENSOR

ENERGIEBESPARING



Hoge afkoelings graad

Degelijke konstruktie

Lage weerstand

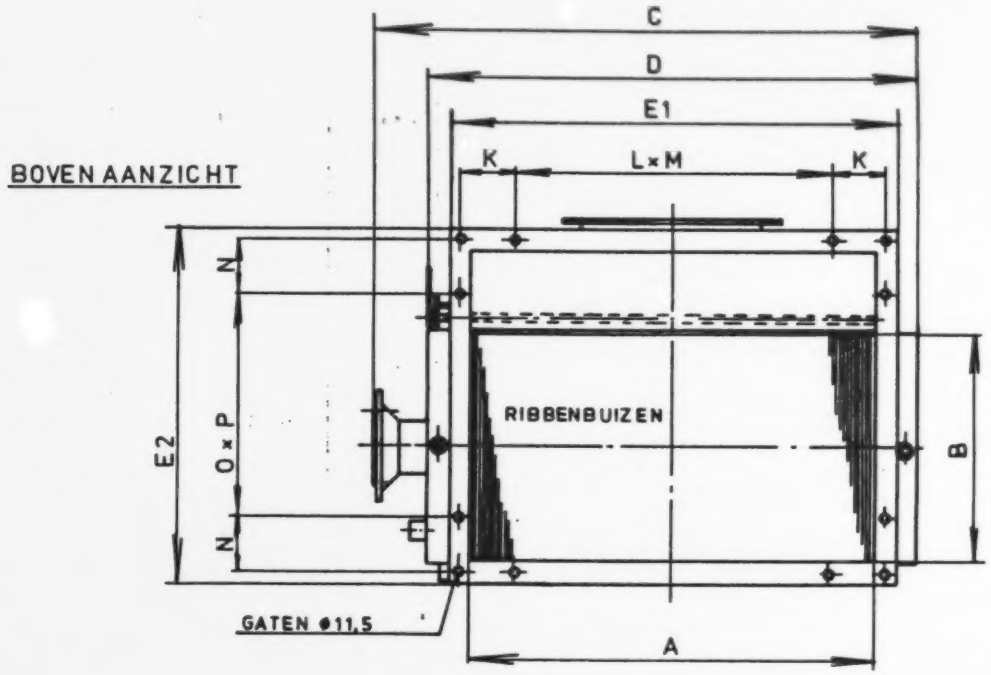
Grote besparing

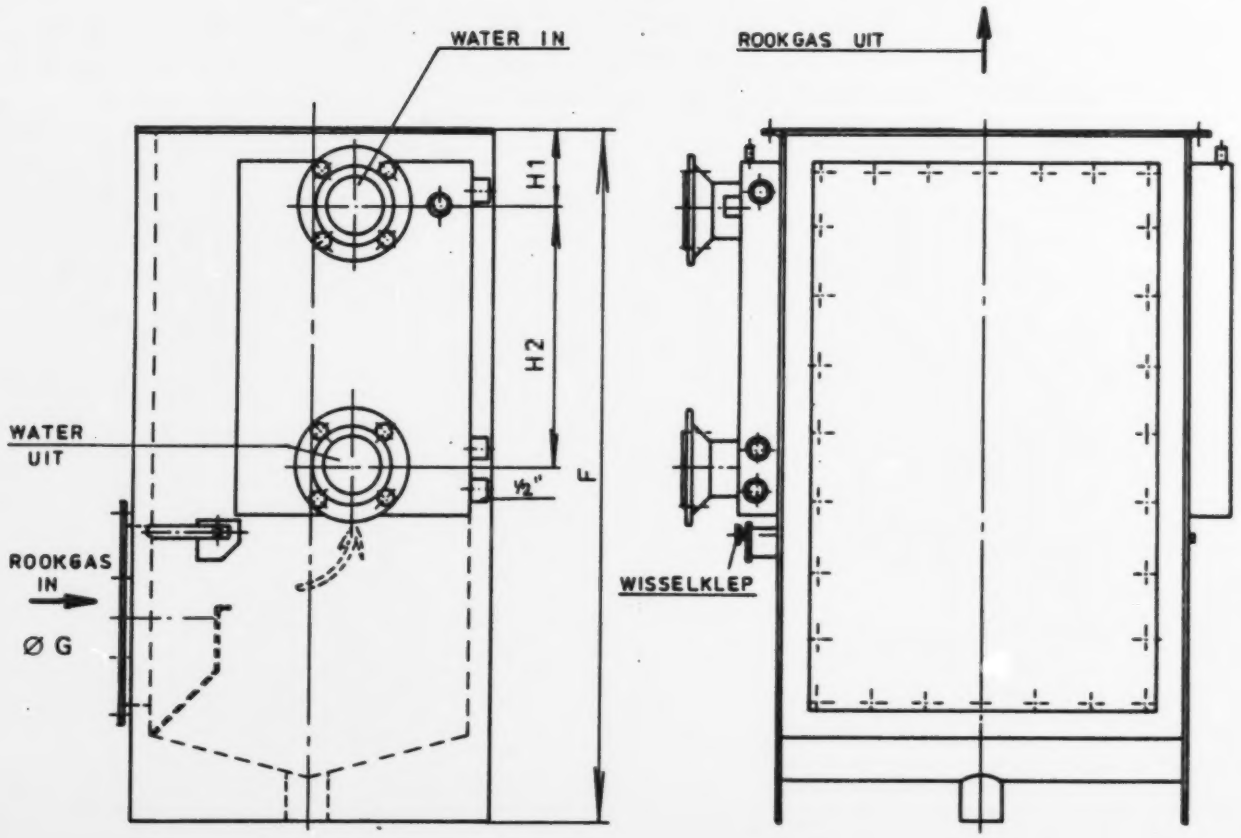
Standaardprogramma tot 7000 kw

Kleine inbouwmaten

van dijk heating

Postbus 29, 3980 CA Bunnik, Holland, Tel. 03405-63844.
Rumpsterweg 2, 3981 AK Bunnik, Holland, Telex 70819.





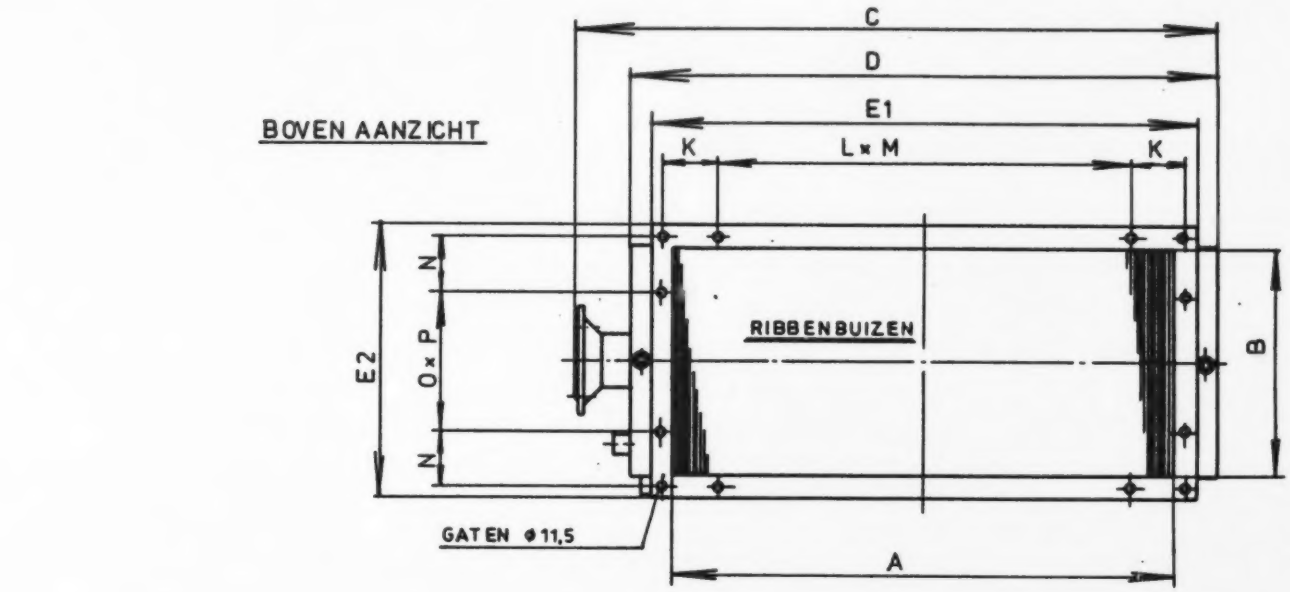
ZIJ AANZICHT

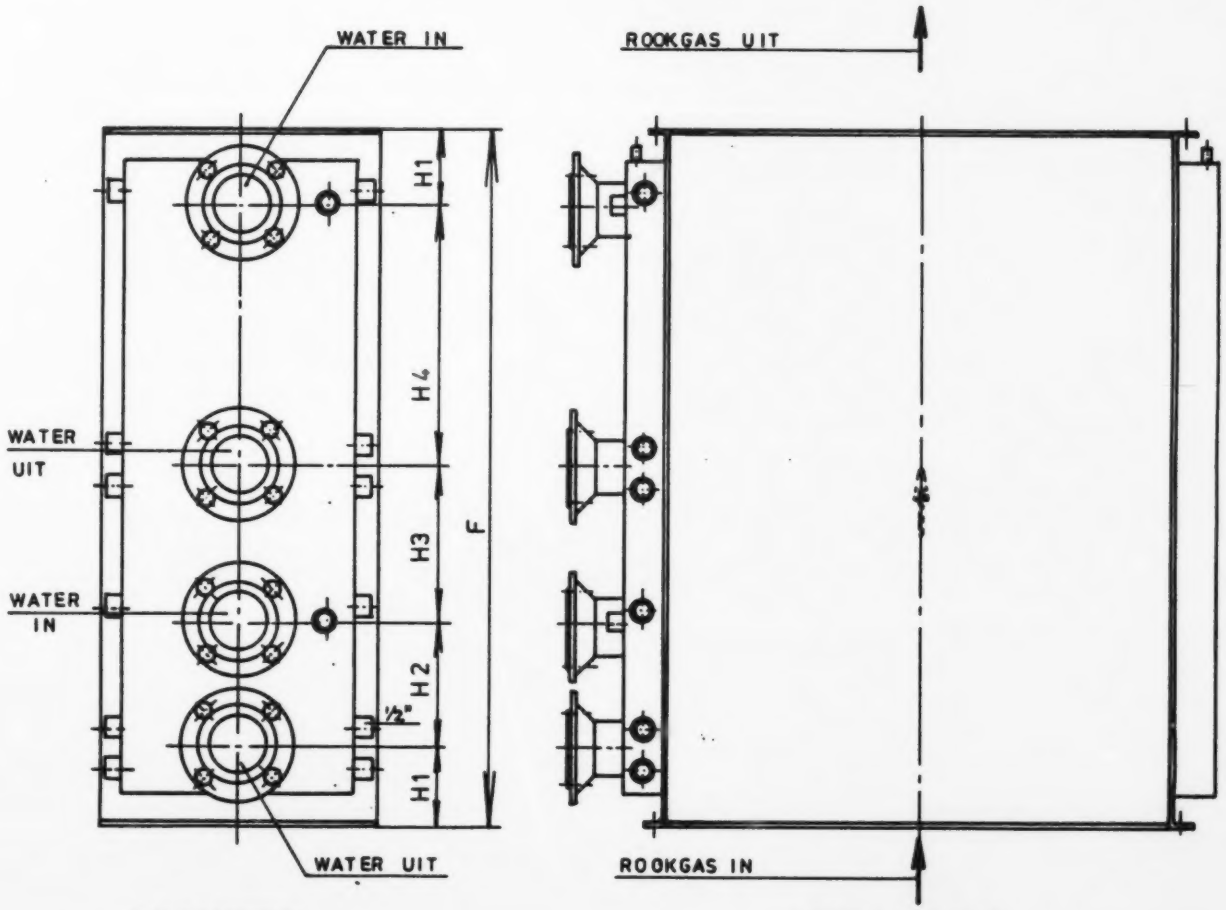
ACHTER AANZICHT

WATERZIJDIG : VOORLASFLENZEN DIN 2631 - ND 6

ROOKGASCONDENSOR type CM 02 t/m C1

van dijk



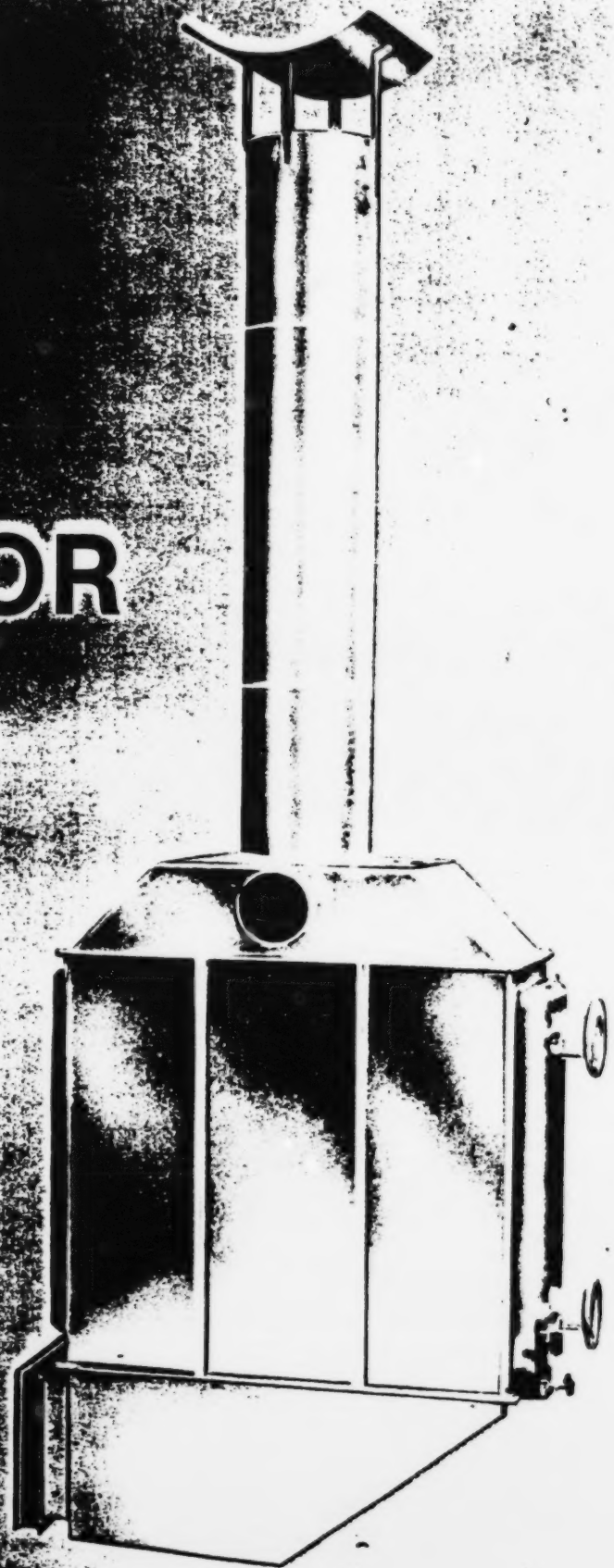


WATERZIJDIG : VOORLASFLENZEN DIN 2631 - ND 6

ROOKGASCONDENSOR type combi C

ROOKGAS CONDENSOR

„een klasse apart"



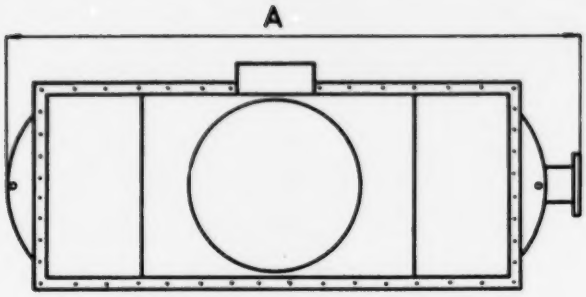
VOOR KETELKAPACITEITEN

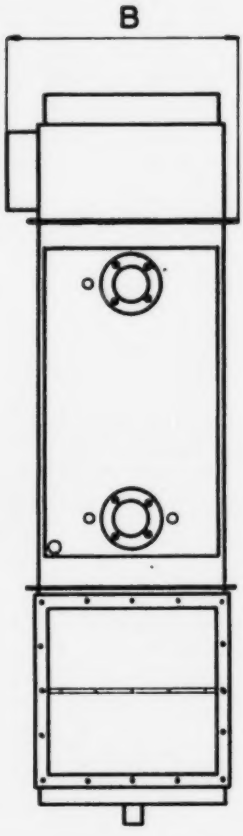
van 250.000-7.000.000 kcal/h

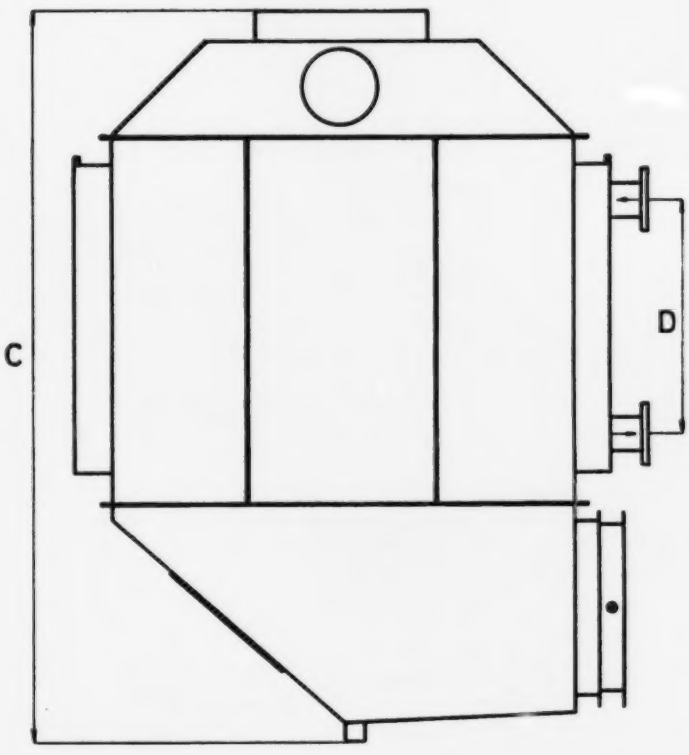
THERMETA B.V.
Industriestraat 32

MAATLIJST

ROOKGAS-CONDENSORS



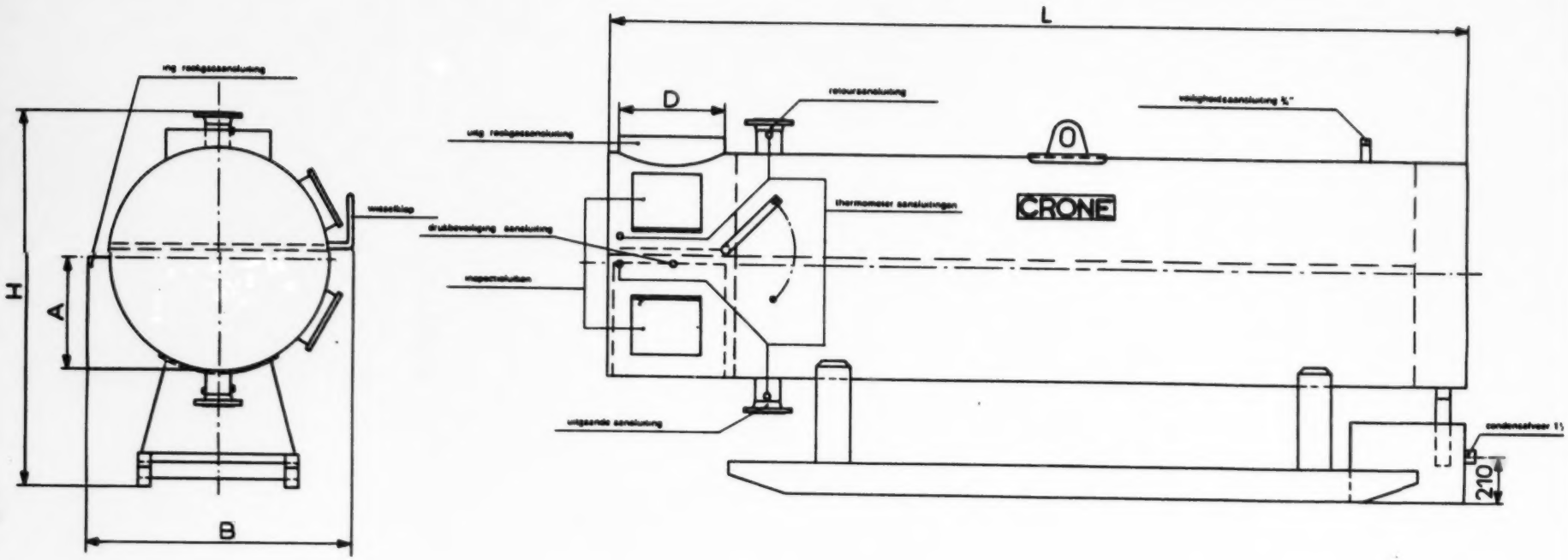




Type	m² V.O.	Ketelkapaciteit in kcal/h	Waterinhoud in ltr.	Lengte „A"	Breedte „B"	Hoogte „C"	D
EKA 4	105	1.000.000	100	1110	535	1975	760
EKA 5	126	1.250.000	120	1110	600	2000	760
EKA 6	156	1.500.000	130	1360	600	2025	760
EKA 7	180	1.750.000	135	1360	600	2050	760
EKA 8	210	2.000.000	140	1610	600	2125	760
EKA 9	262	2.500.000	170	1610	665	2175	760
EKA 10	300	3.000.000	195	1675	730	2225	760
EKA 11	360	3.500.000	210	1925	730	2325	760
EKA 12	405	4.000.000	235	1925	795	2350	760
EKA 13	450	4.500.000	265	1945	860	2375	760
EKA 14	495	5.000.000	275	2095	860	2450	760
EKA 15	594	6.000.000	350	2115	990	2500	760
EKA 16	713	7.000.000	385	2115	990	2800	1010
EKA 6 C	218	1.500.000	155	1360	600	2425	500/500
EKA 7 C	243	1.750.000	180	1360	600	2450	500/500
EKA 8 C	302	2.000.000	210	1610	600	2525	500/500
EKA 9 C	353	2.500.000	248	1610	665	2625	500/500
EKA 10 C	404	3.000.000	257	1675	730	2725	500/500
EKA 12 C	544	4.000.000	320	1925	795	2850	500/500
EKA 14 C	665	5.000.000	365	2095	860	2900	500/500
EKA 15 C	797	6.000.000	450	2115	990	2900	500/500

Maten etc. zijn niet bindend, kunnen om technische redenen zonder voorkennis gewijzigd worden.

CRONE ROOKGASCONDENSORS



Type	C—⅓	C—½	C—¾	C—1	C—1½	C—2	C—2½	C—3	C—4	C—5	C—6	C—7
Ketelcap in Mcal/h	⅓	½	¾	1	1½	2	2½	3	4	5	6	7
Totale lengte L	2500	2500	2600	3600	3600	3750	3750	3850	4000	4000	4250	4250
Totale breedte B	469	560	665	710	850	950	1045	1130	1310	1490	1620	1725
Totale hoogte H	924	1015	1105	1282	1410	1510	1635	1702	1890	2035	2160	2265
Gewicht in kg	540	670	910	1480	2270	2840	3520	4190	5320	6500	7700	8850
Verw. opp. in M²	12	18	27	40	60	80	100	120	160	200	240	280
Diam. uitg. retour	50	80	80	80	100	100	100	100	125	150	150	150
Idem indien op ketelretour	65	80	100	100	100	125	125	150	150	150	150	150
Rookgasaansl. ing. ⊠ inw. A	250	300	350	390	410	430	480	520	620	665	710	755
Rookgasaansl. uitg. ⌀ inw. D	200	250	300	300	350	400	450	500	600	650	700	750

Rookgascondens

Flensaansl. vlg.

Ketel- en Apparatenfabriek W.K. CRONE B.V. Nieuwerkerk aan de IJssel

waste gas recuperator

Save 10 till 15% on your expensive energy!

ECO

Z

zantingh aalsmeer

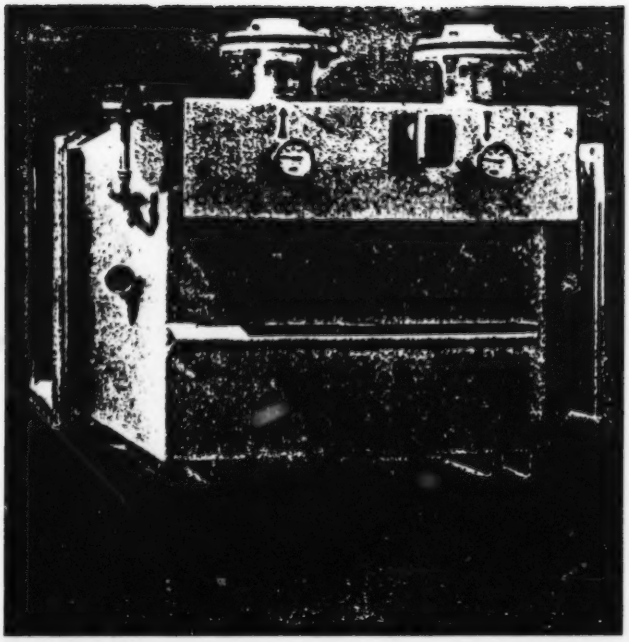
postbox 256
aalsmeerderdijk 473
1430 AG aalsmeer - holland
phone 02977 - 22366
telex 14362 TBZ nl

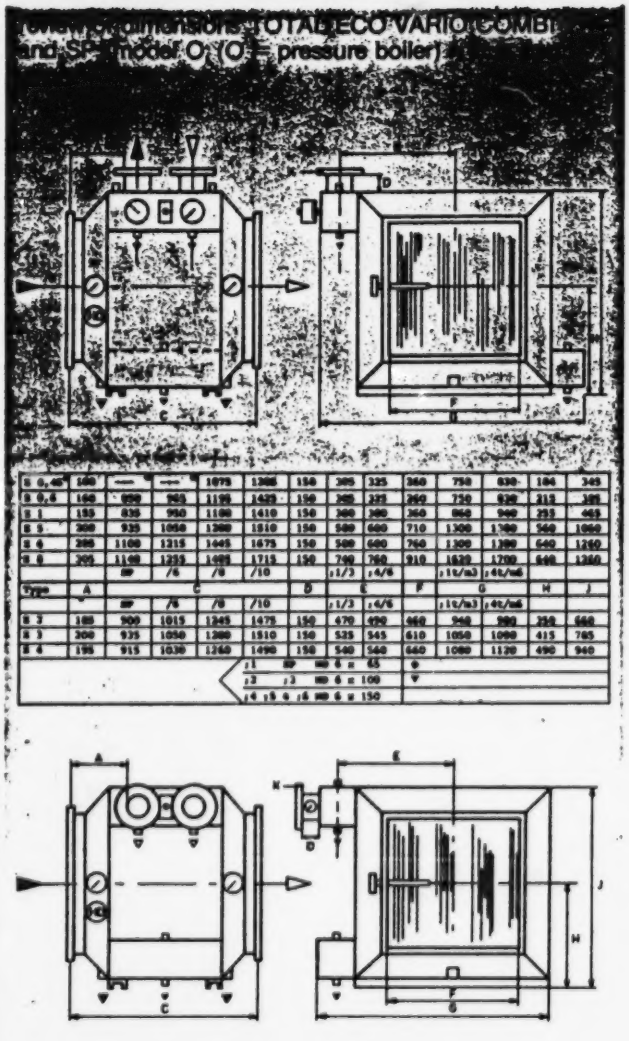
Advantages of this construction

- a large flue gas side heated surface (lamellae)
- a high transmission factor (necessary at small differences of temperature)
- small size (easy to mount)
- very small flue gas resistance which can be overcome by each normal burner
- extension of equipment capacity
- mountable in horizontal and vertical position
- minimum of mounting costs
- minimum of dead weight
- minimum of water contents
- minimum of water resistance

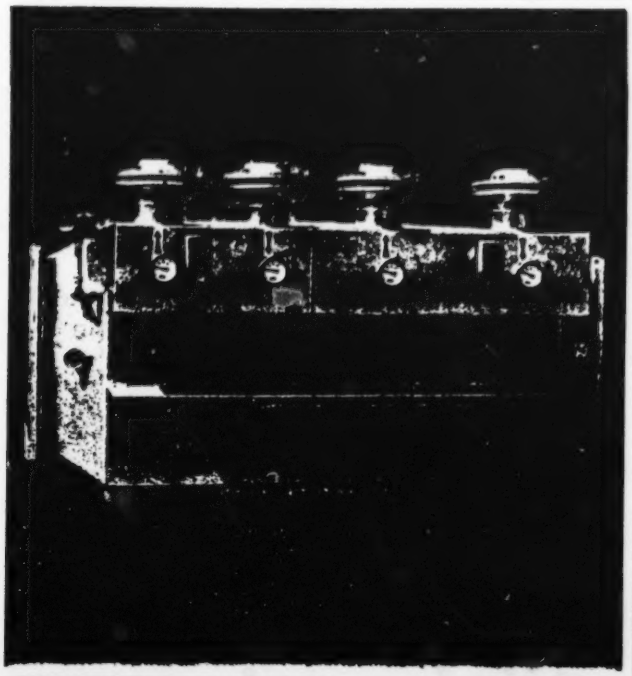
Save your energy from 10 till 15%.

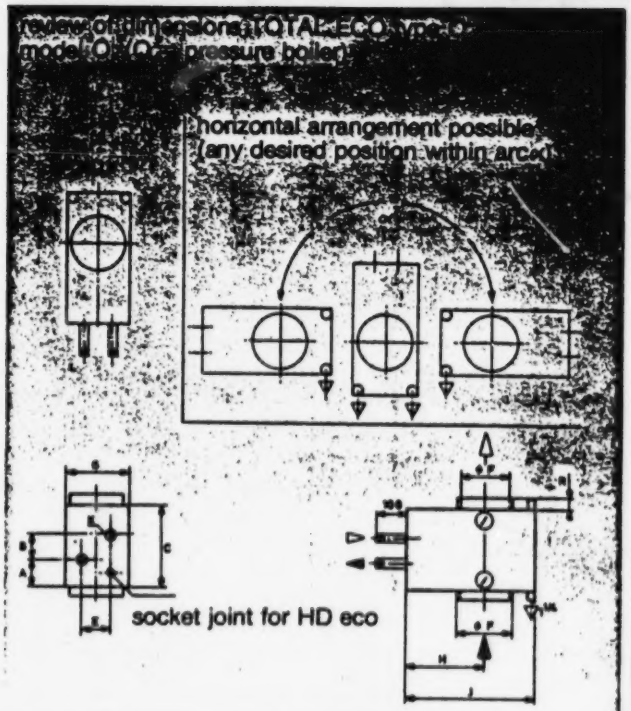
Save 10 till 15% on your expensive energy!





Type	A	B	C	D	E	F	G	H	J
S 2	185	500	1015	1245	1475	150	470	490	660	940	980	250	660
S 3	300	935	1050	1280	1510	150	535	545	610	1050	1090	415	785
S 4	195	915	1030	1260	1490	150	540	540	660	1080	1120	490	940

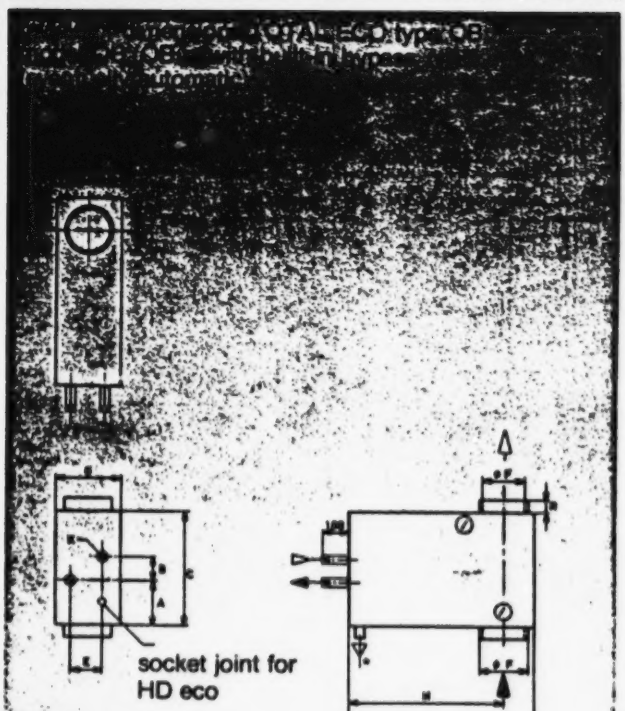




with vertical arrangement, use receptacle for condensate

TYPE	A	B	C	D	E	F	G	H	J	R				K
0,025														
0,05	165	105	440		136	150	275	175	315	50				1"
0,1	195	105	500		136	225	275	250	440	50				1¼"
0,2	180	140	500		198	250	350	285	500	50				2"
0,3	180	140	500		198	250	350	360	650	50				2"
0,45	280	140	700		342	300	510	390	710	50				2½"

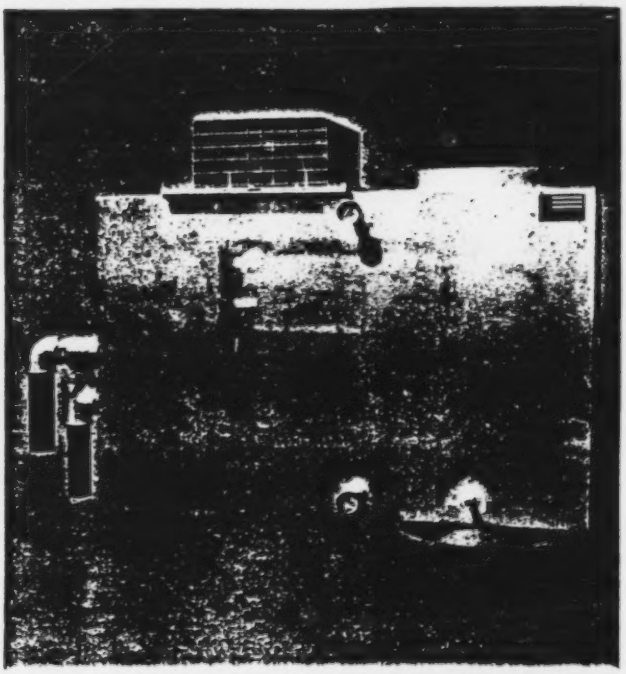
separately supplied clampling thermostat and spring-type safety device tot be mounted on outgoing line.



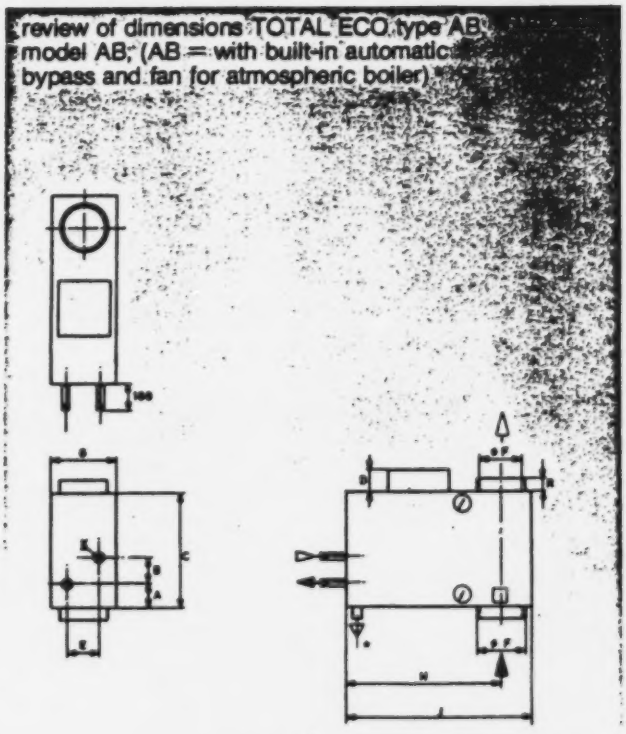
condensate socket joint 1¼"

TYPE	A	B	C	D	E	F	G	H	J	R				K
0,025														
0,05	205	105	600		136	150	275	345	440	50				1"
0,1	205	105	600		136	225	275	490	610	50				1¼"
0,2	205	140	700		198	250	350	370	700	50				2"
0,3	255	140	700		198	250	350	750	925	50				2"
0,45	255	140	750		342	300	510	830	1000	50				2½"

separately supplied clampling thermostat and spring-type safety device to be mounted on outgoing line.



review of dimensions TOTAL ECO type AB
model AB; (AB = with built-in automatic
bypass and fan for atmospheric boiler)



condensate drain socket joint 1¼"

TYPE	A	B	C	D	E	F	G	H	J	R	V	W		K
0,075														
0,05	215	185	680	130	136	150	275	475	560	90	220	50		¾"
0,1	215	185	680	130	136	225	275	525	660	90	220	100		¾"
0,2	170	140	700	130	199	288	250	640	880	90	"	150		1"
0,3	170	140	700	130	199	288	250	815	1000	90	"	150		1"
0,45	190	140	730	150	242	450	340	950	1200	90	"	200		1¼"

separately supplied clamping thermostat and spring-type safety device to be mounted on outgoing line.

specifications subject to change

zantingh aalsmeer

postbox 255
aalsmeerderdijk 473
1430 AG aalsmeer - holland
phone 02977 - 22355
telex 16302 TBZ nl

belgiën: lierseleenweg 63
2580 st. katelijne waver